ASPECTS OF THE BIOLOGY OF THE RED COD *PSEUDOPHYCIS BACCHUS*

A thesis presented for the
degree of Doctor of Philosophy in Zoology
in the University of Canterbury,
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by

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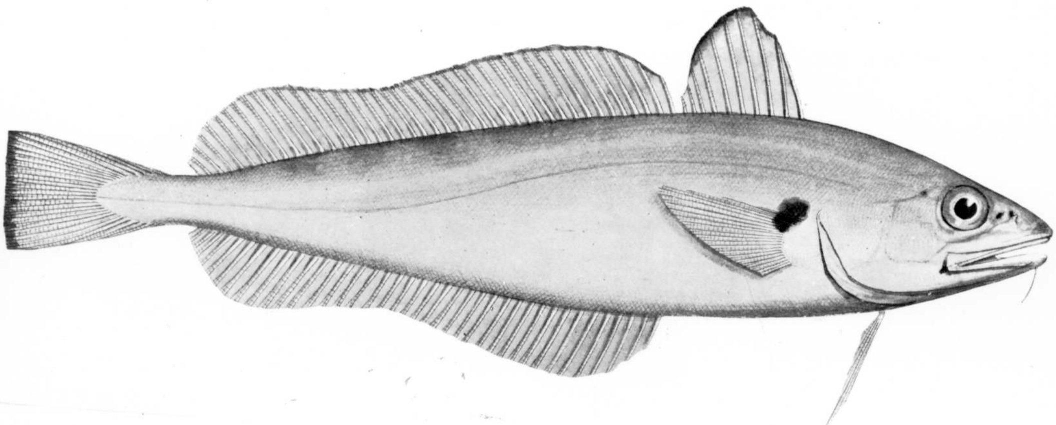


SECTION 1

GENERAL INTRODUCTION

1.1 a Introduction

Codfishes, of the order Gadiformes (Anacanthini), suborder Gadoidei, are moderate to deep water fishes which have a worldwide distribution. The group is best represented in temperate and cold waters,especially in the Northern Hemisphere, where it contains some of the most valuable commercial species found anywhere in the world.

Predominantly bottom-dwelling omnivores, these fishes characteristically have moderately elongate bodies covered with small scales, a tail fin free from dorsal and anal fins, a dorsal fin divided into two or three parts, pelvic fins jugular in position, all fins being without true spines. The mouth is large and terminal, the chin often has a sensory barbel.

In New Zealand waters, codfishes are represented by six families, twelve genera, and fifteen species. Many of these are little known deep water species. Unexploited and seldom seen by New Zealand fishermen, their occurrence in our waters in any quantity has only recently become known through the reports of foreign fishing fleets.

The best known of New Zealand's codfishes is the red cod *Pseudophycis bacchus* (Forster in Bloch and Schneider, 1801). Of all the cods, this species most closely resembles its northern hemisphere counterparts. Elongate with a stout body, it is distinguished from other southern species by its red-grey colour, square-cut tail, body proportions, the number of rays in its fins (first dorsal 9-12, second dorsal 39-48, anal 40-50, caudal 32-36, pectorals 22-26, pelvics 5-6), and by a black spot on the side of the body near the pectoral fins. Averaging 2 kg (to 6.3 kg) in weight and 55 cm (to 120 cm) in length, the red cod is an active wandering marine fish with a range which extends from the shore into depths of over 750 metres (Shuntov, pers. comm.). Fast growing and of relatively short lifespan, this primarily ground-dwelling predator moves throughout the levels of the sea at times, feeding on a wide range of marine animals.

FIGURE 1

Place names North Island, New Zealand.

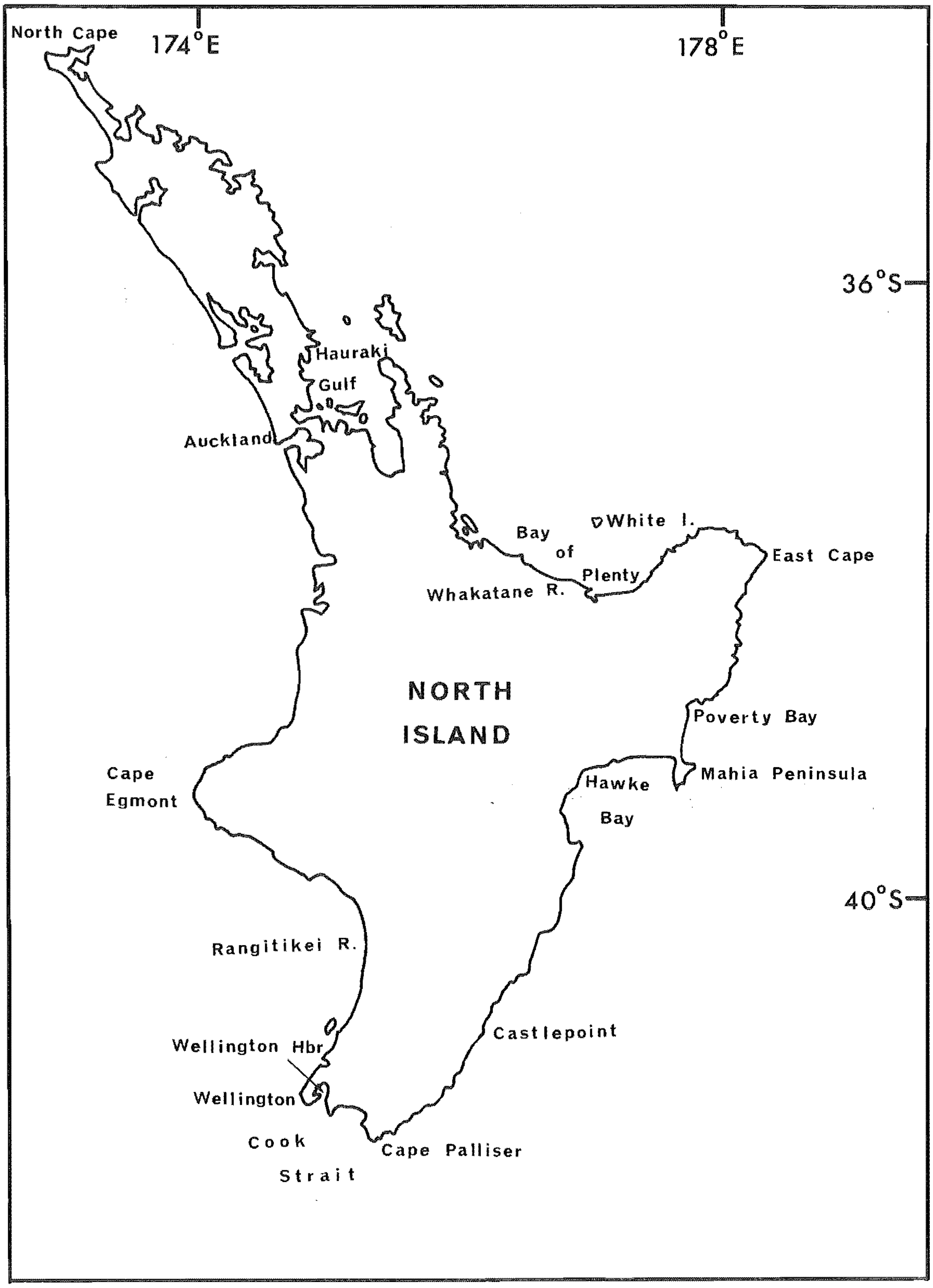
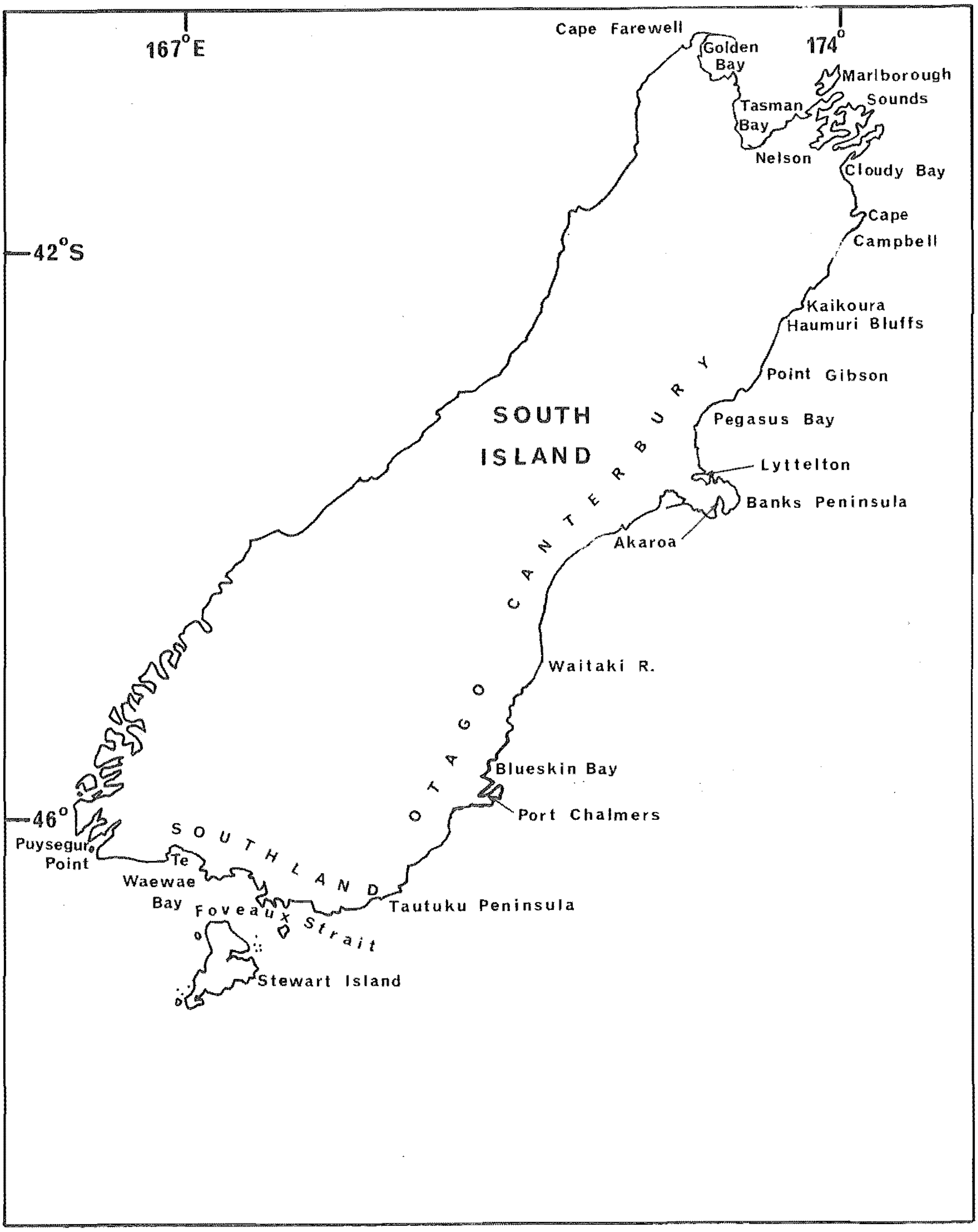

North Cape
174°E
178°E
36°S
Hauraki
Gulf
Auckland
Bay
of
Plenty
White I.
East Cape
Whakatane R.
NORTH
ISLAND
Poverty Bay
Mahia Peninsula
Cape
Egmont
Hawke
Bay
40°S
Rangitikei R.
Castlepoint
Wellington Hbr
Wellington
Cook
Strait
Cape Palliser

FIGURE 2

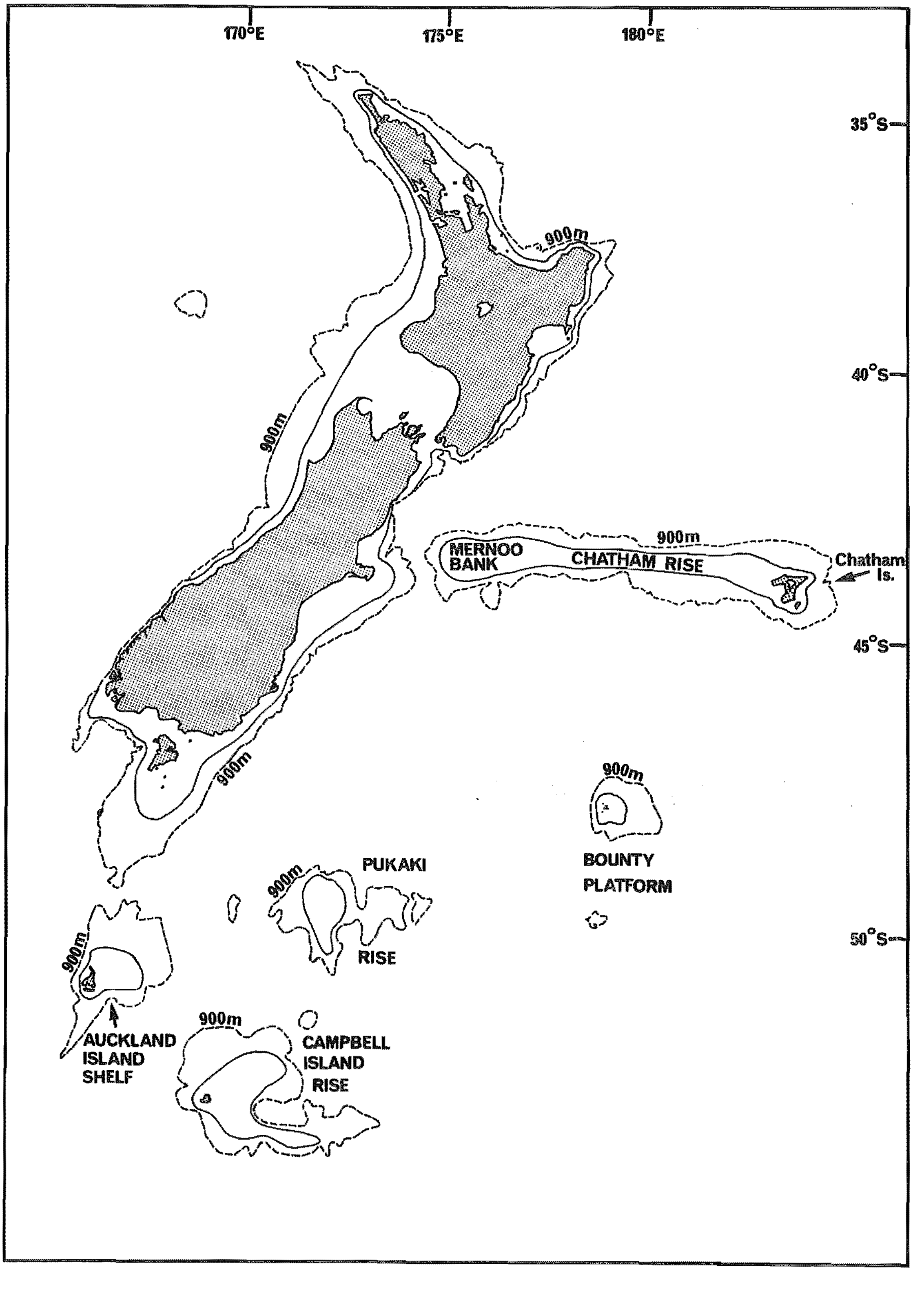
Place names South Island, New Zealand,



167°E
174°
42°S
46°
Cape Farewell
Golden Bay
Tasman Bay
Nelson
Marlborough Sounds
Cloudy Bay
Cape Campbell
Kaikoura
Haumuri Bluffs
Point Gibson
Pegasus Bay
Lyttelton
Banks Peninsula
Akaroa
SOUTH ISLAND
CANTERBURY
OTAGO
Waitaki R.
Blueskin Bay
Port Chalmers
SOUTHLAND
Tautuku Peninsula
Puysegur Point
Te Waewae Bay
Foveaux Strait
Stewart Island

FIGURE 3

Distribution of the red cod *Pseudophycis bacchus* in the New Zealand region (Solid line - distribution; broken line - 900 m depth contour).


170°E
175°E
180°E
35°S
40°S
45°S
50°S
900m
900m
900m
900m
MERNOO
BANK
CHATHAM RISE
Chatham
Is.
900m
BOUNTY
PLATFORM
900m
PUKAKI
RISE
900m
AUCKLAND
ISLAND
SHELF
900m
CAMPBELL
ISLAND
RISE

1.1 b Distribution (Figs 1, 2, and 3)

The red cod is distributed in the coastal and offshore waters of New Zealand and its offshore Islands, preponderantly to the south of this range. The distribution was first described by J.R. Forster, naturalist on the second of James Cook's voyages to New Zealand (1772-1775), in the words "Habitat in mari alluente insulam australem Novae Zeelandiae" (See Lichtenstein, 1844). Various general and scientific writings testify to this (Hutton and Hector, 1872; Dambeck, 1879; Phillipps, 1921, 1927b, 1927c; Fowler, 1940; Graham, 1953; Parrott, 1957; Doogue and Moreland, 1969; Anon., 1972a; Doak, 1972; Waugh in Williams, 1973).

More specific occurrences have been reported for the following areas: Auckland and north of Auckland (Phillipps and Hodgkinson, 1922; Phillipps, 1949; Russell, 1969, 1971a, 1971b); Bay of Plenty (Tong and Elder, 1968; Godfriaux, 1974); Wellington (Phillipps, 1948, 1949; Parrott, 1958; Elder, 1966); Marlborough Sounds (Richardson, 1843; Günther, 1880a; Whitehead, 1968); Canterbury (Ayson, 1900; Waite, 1909; Archey, 1927; Shuntov, 1970, 1972; Coakley, 1971; Anon., 1972b; Watkinson and Smith, 1972; Ryan, 1974); Otago (Hector, 1875; Hutton, 1875; Thomson, P., 1877, 1878, 1879; Ayson, 1900, 1907; Thomson, G.M., 1906; Waite, 1909; Phillipps, 1918, 1949; Thomson and Anderton, 1921; Carter and Malcolm, 1926; Benham, 1936, 1944; Graham, 1939, 1953; Manter, 1954; Graham, J., 1963); Southland and West Coast South Island (Churchman, 1965; Howell, 1966); Mernoo Bank - Chatham Rise (Moreland in Knox, 1957; Iwai, Nakamura, Inada, Ikeda, Sato and Hatanaka, 1970; Shuntov, 1970, 1972; Anon., 1972b); Pukaki Rise - Campbell Rise - Auckland Island Shelf (Anon., 1972a, 1972b; Iwai et al, 1972; Shuntov, pers. comm.); and Chatham Islands (Young, 1929).

Red cod have also been reported from Australian waters (Aust) or from the specific parts of Australia, South Australia (SA), New South Wales (NSW), and Tasmania (Tas). Allport (cited by Johnston, 1882) reported occurrences in SA, NSW and Tas. Other reportings were filed by Ogilby (1886) (NSW), Waite (1899, 1904) (Aust), McCulloch (1922, 1929) (NSW), Waite (1921, 1923, 1928) (SA), Lord and Scott (1924) (Tas), Lord (1927) (Tas), Norman (1937) (SA, NSW), Munro (1938) (SA, NSW), Scott (1962) (SA, NSW, Tas), Whitley (1962, 1964) (Aust), Moreland (1963) (Aust), Paul (in McLintock, 1966) (Aust), Heath and Moreland (1967) (Aust), Cowper (1970) (SA, Tas), and Scott, Glover, and Southcott (1974) (SA).

There is doubt regarding the validity of reportings of Australian occurrences. This stems from evidence of misidentification of the Australian rock cod, *Pseudophycis barbatus* (*Physiculus barbatus*), for the red cod. Waite made this mistake when he deposited two specimens of *P. barbatus* in the Australian Museum under the label *P. bachus* (Dr J.R. Paxton, Curator of Fishes, Australian Museum, pers. comm.). As most workers subsequent to Waite merely reiterated Waite's findings, it is likely that these records are erroneous. This view is supported by Dr I.S.R. Munro, Principal Research Scientist, Commonwealth Scientific and Industrial Research Organization, Australia, and by M.H. Walker, biologist, Tasmania (pers. comms).

Cod specimens were similarly confused in the South Australian Museum (Scott, 1962). On the strength of this finding, Scott stated "The record for South Australia [of *P. bacchus*] needs verification."

Regarding Tasmanian reportings, Walker (1972) found no red cod during his work in that area, and further, he discounted early reportings when he stated "... evidence suggests that the earlier reports are based on misidentified specimens of *P. barbatus*."

It is unlikely therefore that *P. bacchus* has an Australian distribution.

1.2 Previous work

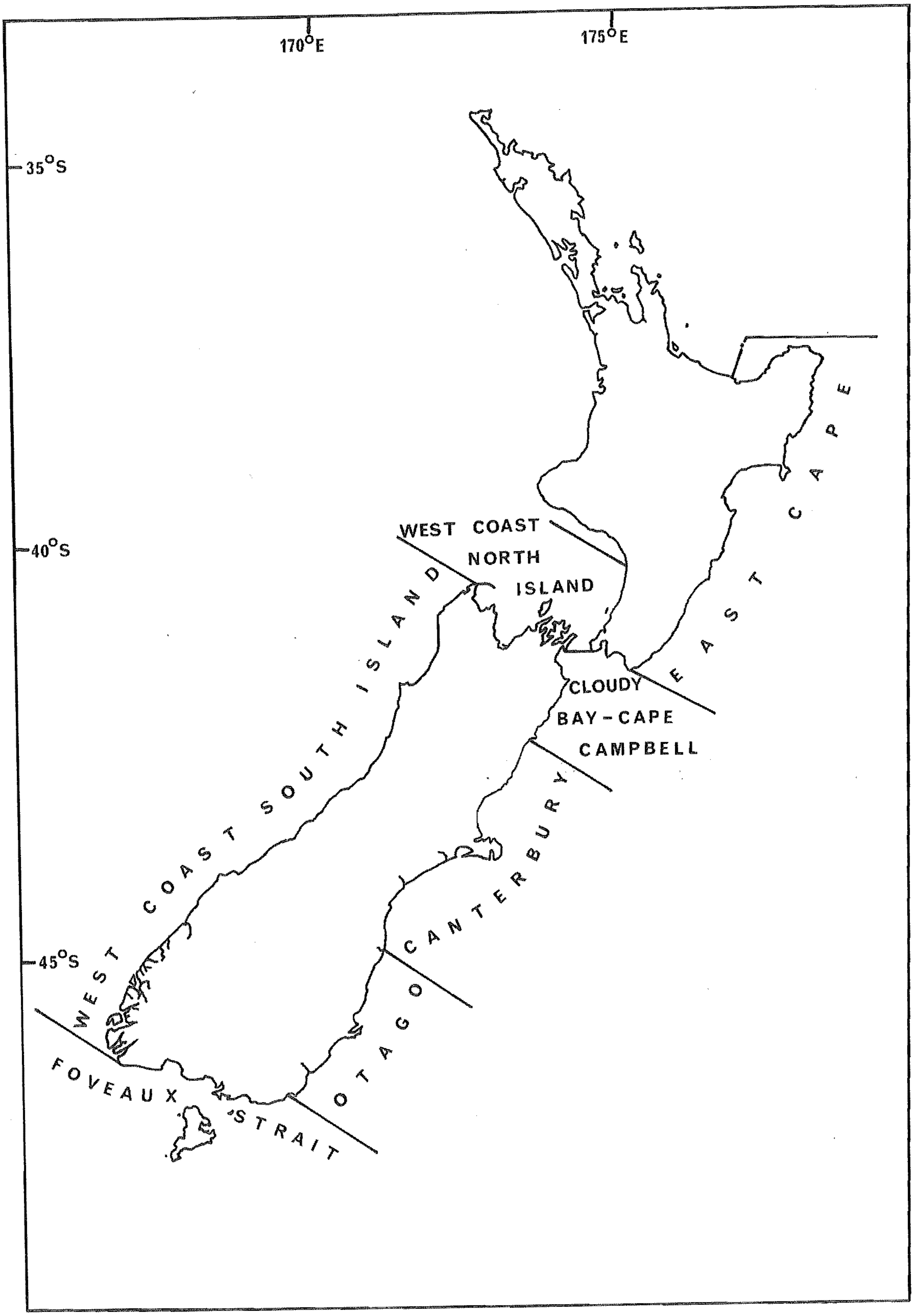
Apart from works mentioned above, there is a considerable amount of largely insubstantial writing on red cod in the literature. These works may be conveniently considered under the headings (1) brief synopses, (2) taxonomy and systematics, (3) anatomy, (4) the red cod fishery, (5) age and growth, (6) food and feeding, (7) reproduction, (8) food value of red cod, (9) parasites, and (10) miscellaneous.

The works in categories (2), (4), (5), (6), and (7) will be discussed in relevant sections later in this thesis. Works which occur under the other headings are:

(1) Brief synopses - Hector (1884, 1886); Sherrin (1886); Hutton (1896); Waite (1911); Phillipps (1927a); Moreland (1963); Paul (<u>in</u> McLintock, 1966); Heath and Moreland (1967). (Various other brief synopses are listed in Section 1.1 b).

FIGURE 4

Red cod study areas around the New Zealand coast.


170°E
175°E
35°S
40°S
45°S
WEST COAST NORTH ISLAND
EAST CAPE
WEST COAST SOUTH ISLAND
CLOUDY BAY-CAPE CAMPBELL
CANTERBURY
OTAGO
FOVEAUX STRAIT

(2) Anatomy - Parker (1882, 1883); Beattie (1891); Johnston (1938).

(3) Food value of red cod - Johnson (1921); Carter and Malcolm (1926); Malcolm (1926); Cunningham (1937); Shorland (1937, 1948, 1950).

(4) Parasites - Thomson (1890); Laird (1949, 1951, 1952); Manter (1954); Robinson (1955, 1959); Meglitsch (1960); Howell (1966); Hewitt and Hine (1972).

(5) Miscellaneous - Parker (1882); Thomson (1892); Thomson and Thomson (1923); Frost (1924, 1926, 1933); Rapson (1940); Gorman (1963); Street (1964); Anon. (1965).

1.3 Aim and aspects of the study

The aim of this study was to gain an understanding of the biology and ecology of the red cod in New Zealand waters. Aspects studied were:

(a) Taxonomy and systematics,

(b) The red cod fishery,

(c) Length frequency, age and growth,

(d) Food and feeding,

and (e) Reproduction.

1.4 The study areas

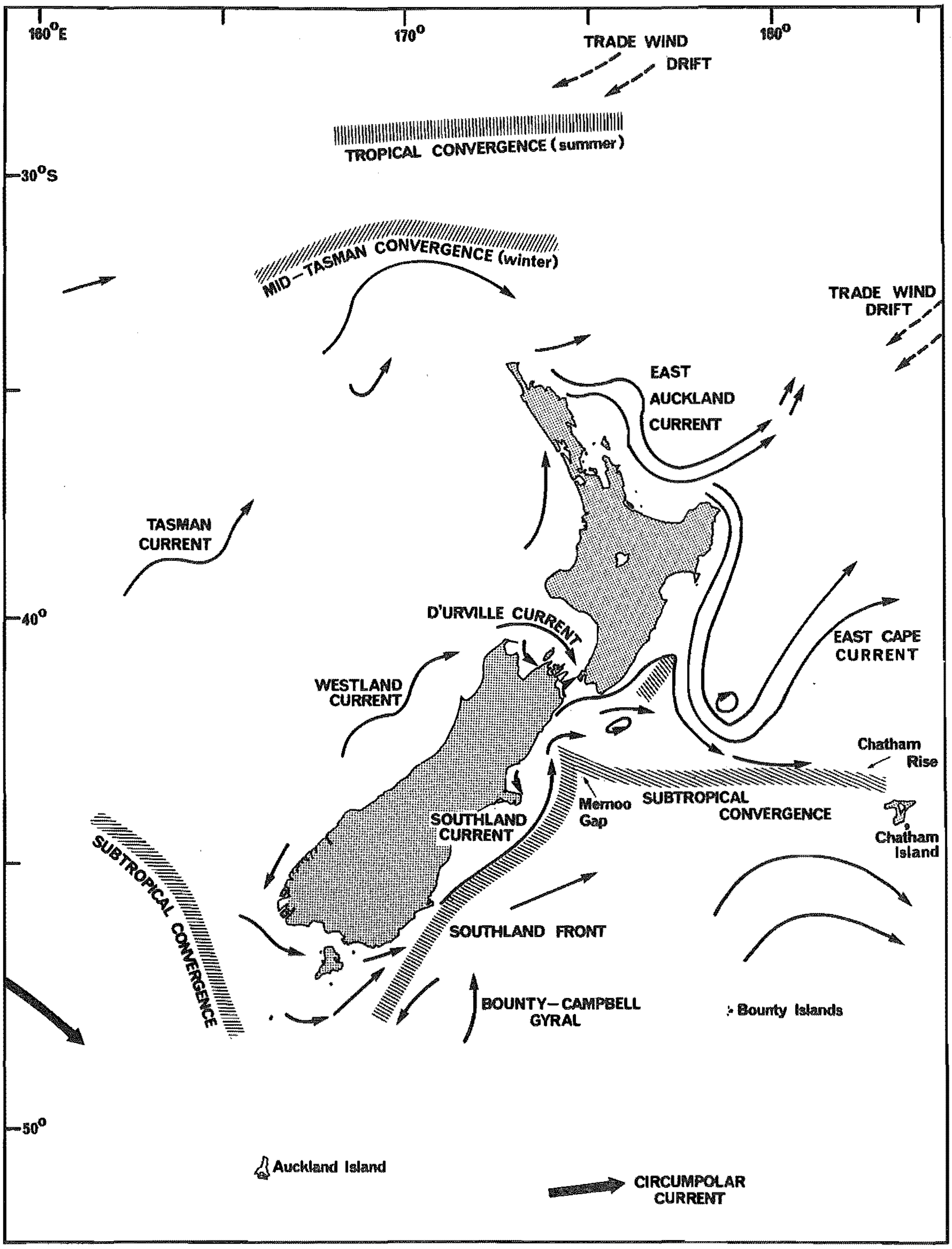
1.4 a Introduction

Samples of red cod were obtained from 7 study areas around the New Zealand coast (Fig. 4). The main study area was Canterbury. It is only here that a full range of samples was taken and full recordings of environmental parameters (water temperature and light intensity in relation to depth) made. This was during the period October 1971 - October 1972.

Occasional samples came to hand from other areas (See Fig. 4). However, owing to limited facilities and finance during the present study, it was sometimes impossible to monitor environmental parameters in these areas. In these instances, other workers' findings are reported with due acknowledgement. Where additional environmental information is available from other sources, such as area bathymetry, oceanic circulation, and salinities, this too is reported with acknowledgement.

FIGURE 5

Oceanic circulation around New Zealand (after Heath, 1973).


160°E
170°
180°
30°S
40°
50°
TRADE WIND DRIFT
TROPICAL CONVERGENCE (summer)
MID-TASMAN CONVERGENCE (winter)
TRADE WIND DRIFT
EAST AUCKLAND CURRENT
TASMAN CURRENT
D'URVILLE CURRENT
WESTLAND CURRENT
EAST CAPE CURRENT
Chatham Rise
Mernoo Gap
SUBTROPICAL CONVERGENCE
Chatham Island
SOUTHLAND CURRENT
SUBTROPICAL CONVERGENCE
SOUTHLAND FRONT
BOUNTY-CAMPBELL GYRAL
Bounty Islands
Auckland Island
CIRCUMPOLAR CURRENT

It was intended that analyses be carried out on fish samples from the Chatham Islands as well. However, during a 4.5 day period of trawling in this area in November 1972, only 8 red cod were captured, a sample too small to warrant analysis.

1.4 b New Zealand, its hydrology and oceanic circulation (Fig 5)

There have been many studies on the hydrology and oceanic circulation in the New Zealand region. Early work is summarised by Garner (1959, 1961, 1962), Brodie (1960), and Garner and Ridgway (1965). Heath (1973) has reviewed the more recent work. He noted that the recent emphasis has been on "... research into the physical properties of New Zealand waters..." by "... the analyses of temperature, salinity, depth data collected from a series of hydrological surveys..."

New Zealand is at the centre of five main water masses which have distinctive temperature-salinity characteristics. These are the Surface Subtropical and Subantarctic Waters, Antarctic Intermediate Water, Pacific Deep Water and Bottom Water. Though initially distinctive (See Heath, 1973 pp. 125-6), they do not remain so, but are subjected to mixing in ocean currents and modification by meteorological influences. These bodies of water finally impinge upon the New Zealand region by way of oceanic current systems.

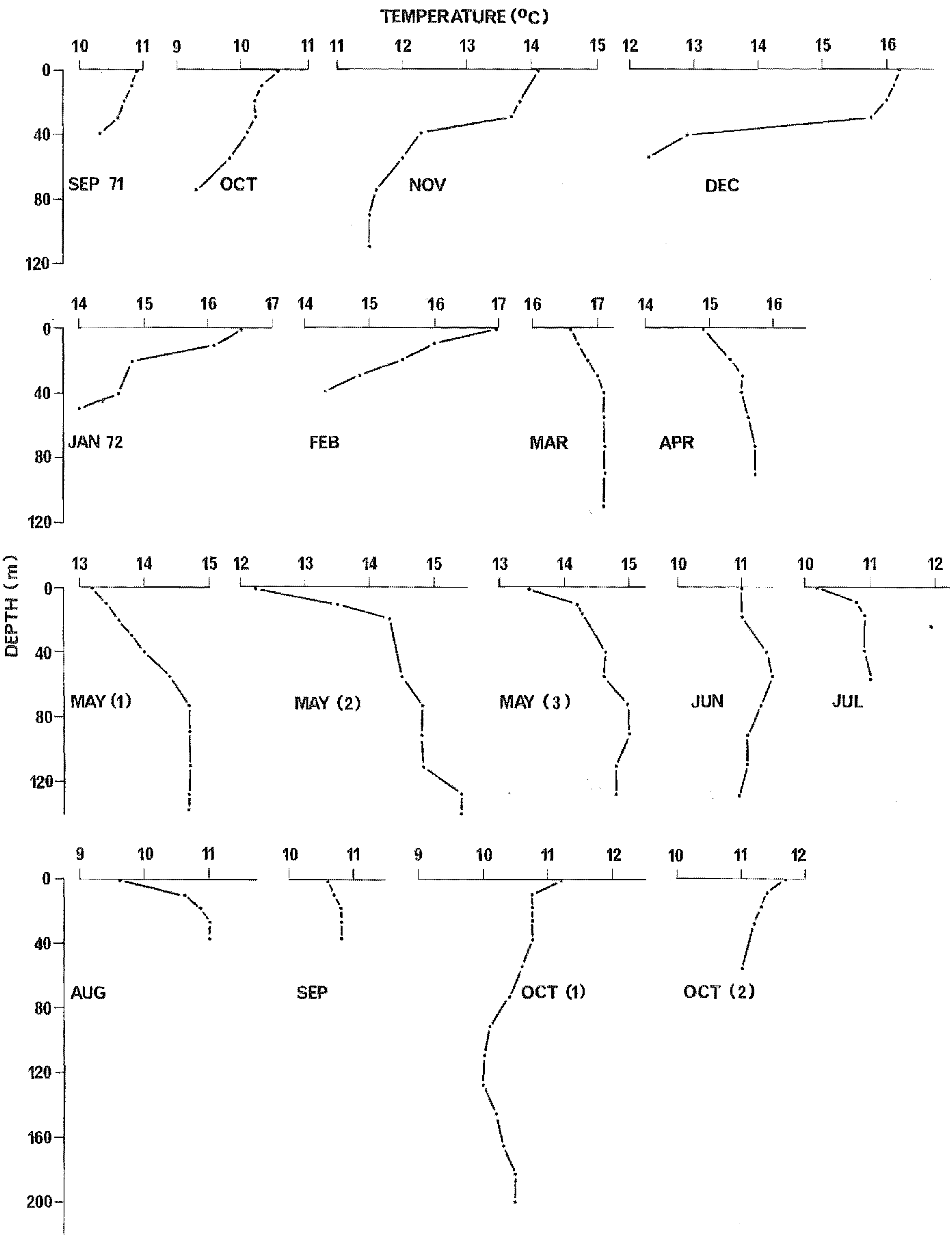
1.4 c Canterbury, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

The Canterbury area, on the east coast of the South Island of New Zealand, extended from the Haumuri Bluffs (42°33'S) near the Kaikoura Peninsula, south to the Waitaki River mouth (44°55'S). This area is affected primarily by the Southland Current, a predominantly subtropical current which has its origin in the Tasman Current, flowing eastwards through Foveaux Strait and south of Stewart Island before turning north along the east coast of the South Island (Garner, 1961, 1969; Garner and Ridgway, 1965; Heath, 1971a, 1972, 1973).

South of Banks Peninsula, this current is, at the surface, mainly warm, saline Subtropical Water. However, Subantarctic Water also flows northward along the east coast of the South Island, and this water provides a cooler, less saline aspect to the Southland Current (Jillett, 1969). It is generally an offshore component. Inshore of the warm Subtropical component is a third component of the Southland

FIGURE 6

Water temperature - depth profiles for the Canterbury area, September 1971 - October 1972 (For details of time, conditions, and position, see Table 1).


TEMPERATURE (°C)
DEPTH (m)
SEP 71
OCT
NOV
DEC
JAN 72
FEB
MAR
APR
MAY (1)
MAY (2)
MAY (3)
JUN
JUL
AUG
SEP
OCT (1)
OCT (2)

Current, the cooler, less saline, neritic water.

In the region of the Mernoo Gap, there is mixing of the components of the Southland Current with the result that it acquires a cool low-salinity character north of Banks Peninsula.

There have been various interpretations of the hydrological data available in the literature, and that amassed by individual workers, in the description of the current systems near Kaikoura (Garner, 1953, 1959; Brodie, 1960; Burling, 1961; Heath, 1971a, 1972, 1973). The most recent synthesis is Heath's: "The Southland Current branches near Kaikoura with one component meandering towards the east and the other continuing northwards on the continental shelf and slope" (Heath, 1973 p. 129).

Pegasus Bay, from which most of the Canterbury area samples were obtained, is out of the main flow of the Southland Current. Banks Peninsula, lying in the path of the Southland Current, diverts most of its flow past Pegasus Bay, although much of the water in the bay is derived from the Southland Current. There is apparently a south flowing counter-current system in Pegasus Bay which Heath (1970) suggested is generated by the predominant northerly winds in the bay, as described by Garnier (1958). He further suggested that if this is so, then the water in Pegasus Bay is largely a mixture of water derived from the Southland Current, and cool river water which is driven south by northerly winds. The presence of very low salinities in Pegasus Bay, indicating considerable fresh-water dilution, was established by Garner (1961). Dawson (1954) also described such dilution in Pegasus Bay as well as other aspects of its hydrology.

During this study, water temperature and light intensity in relation to depth were recorded in the Canterbury area, for the months September 1971 - October 1972 (See Fig. 6 and Table 1). Details of time of day, conditions, and position for both water temperature and light intensity are presented in Table 1. Adequate depth contour representations which might be consulted in relation to the Canterbury area are figured by Knox (1969, Figs 1 and 2).

The temperature readings show that there was an annual temperature range at the surface of 7.3°C. This is higher than the figure of 5.5°C recorded for this area by Garner (1953, 1959). However, both the minimum and maximum temperatures of the range were taken at inshore stations (Table 1). The February 1972 reading of 16.9°C was probably excessively high owing to insolation in shallow water and coastal protection. Conversely, the August, 1972, minimum of 9.6 C was probably excessively depressed through convective cooling and the depletion of the reserve of heat available in subsurface waters. This process would occur at an increasing rate with decrease in depth.

If temperature readings were made during February and August, 1972, in more stable deeper water in Pegasus Bay, it is likely that the minima and maxima would not have been so large. The annual temperature range would then have been closer to reported ranges in the literature.

Table 1: Light intensity in relation to depth of water in the Canterbury area, September 1971 - October 1972.

Month, Time, Conditions, Position	Depth (m)	Light (lux)*	Month, Time, Conditions, Position	Depth (m)	Light (lux)*
Sep. 1971, 1120 h, clear, sunny, 43°07'S, 173°09'E	0 9 18 27 37	91 000 18 500 11 100 5 000 266	Oct. 1971, 1600 h partly overcast, 43°04'S, 193°23.5'E	0 9 18 37 55 73	11 100 7 900 3 050 295 116 24
Nov. 1971, 1515 h, partly overcast, 43°35'S, 173°35'E	0 18 37 55 73 91 110	14 400 4 100 1 100 86 30 14 4	Dec. 1971, 1500 h, partly overcast, 43°24'S, 173°27'E	0 9 18 37 55	21 200 9 000 3 850 1 320 21
Jan. 1972, 1430 h, partly overcast, 43°03'S, 173°10'E	0 9 18 37 46	18 500 6 100 2 250 310 40	Feb. 1972, 1430 h, partly overcast, 43°25'S, 173°13'E	0 9 18 27 37	23 700 4 600 1 860 860 22
Mar. 1972, 1730 h, partly overcast, 43°27'S, 173°38'E	0 9 18 27 37 55 73 91 110	1 100 580 470 290 224 61 37 14 4	Apr. 1972, 1700 h, overcast, 43°28'S, 173°47'E	0 18 37 55 73 91	2 200 1 390 970 250 122 32

Table 1: Continued

Month, Time, Conditions, Position	Depth (m)	Light (lux)*	Month, Time, Conditions, Position	Depth (m)	Light (lux)*
May 1972(1), 1260 h, overcast, 43°33.5'S, 173°58'E	0 18 37 55 73 91 110 128 137	9 700 1 215 1 110 410 166 57 15 8 7	May 1972(2), 1155 h heavy overcast, 44°37'S, 172°32'E	0 18 37 55 73 91 110 128 146 165 183 201	3 300 180 13 7 5 5 5 5 5 5 4 4
May 1972(3), 1900 h, partly overcast, 43°05'S, 173°38'E	0 9 18 37 55 73 91 110 128	425 26 13 7 4 4 4 4 4	Jun. 1972, 1600 h overcast, 43°30'S, 173°33'E	0 18 37 55 73 91 110 128	1 575 395 97 20 9 4 4 4
Jul. 1972, 1130 h, clear, water cloudy, 43°12'S, 173°04'E	0 9 18 27 37 46	25 500 1 455 101 17 10 4	Aug. 1972, 1030 h, clear, water cloudy, 43°21'S, 173°06'E	0 9 18 27 37	75 000 2 030 970 150 15
Sep. 1972, 1130 h, partly overcast, 43°12'S, 173°00'E	0 9 18 27 37	37 000 2 400 650 91 43	Oct. 1972(1), 1730 h, partly overcast, 43°14'S, 173°44'E	0 18 37 55 73 91 110 128 146 165 183 201	7 550 1 480 335 100 24 12 5 3 3 3 3 2
Oct. 1972(2), 1045 h, clear, sunny, 43°31'S, 173°16'E	0 9 18 27 55	45 000 9 700 1 660 272 130	* 1 lux = 10.764 foot-candles; 1 foot candle = the illumination of a surface at a uniform distance of 1 foot from a symmetrical point source of 1 candle.		

The spring-summer temperature - with - depth profiles in Figure 6 illustrate the effects of insolation and coastal protection. The temperatures in surface waters were consistently higher than temperature of subsurface waters. These large negative thermal gradients (as defined by Houtman, 1965) were also found by Jillett (1969) off the Otago coast. The autumn-winter gradients were quite different however. They were all positive to a greater or lesser degree. Usually, subsurface temperatures vary little with depth during autumn and winter. The cooling in surface waters results in convective overturn which breaks down the thermal stratification of summer. Jillett (1969) found an isothermal water column in Otago waters from late autumn until spring. Garner (1969) allowed that there might even be a slight increase of temperature with increasing depth in winter, due to a general small increase in salinity in deeper waters at this time. There is a positive correlation between salinity and water temperature in the oceanic situation.

In Figure 6, the extent of the autumn-winter gradients was quite large. This was particularly exaggerated by the large depression of temperature at the surface (See temperature profiles for May 1972(2), and August 1972). Garner (1969, p. 206) suggested that the presence of fresh water run-off from the land could depress surface water temperatures.

Light intensity with depth was also monitored during the present study, using a light-dependent resistor wired into a metered electrical circuit. For each set of readings, time of day and overhead conditions were noted (See Table 1).

Light is seldom considered, even less seldom measured by biologists in their endeavours to describe the physical characteristics of the environment. It is however, a feature of some importance. As Klugh (1927) described it: "The measurement of light penetration into the sea... is of fundamental importance in studies of the life-conditions of aquatic organisms."

Light readings in this study were taken to provide some indications of the extent of the decrease in illumination with increasing depth. Because of the cursory nature of sampling this parameter (maximum of 3 profiles measured per month), and the inconsistency in sampling time and station positions, this work must necessarily be regarded as preliminary in nature.

The decrease in light with increasing depth may be examined briefly. Consulting the data for September 1971 in Table 1, it can be seen that a clear sunny day at that time yielded a surface light reading of 91 000 lux (See end of Table 1 for explanation of lux). At a depth of 9 m, only 18 500 lux were detected, 20.33% of the surface reading. At 18 m, this percentage fell to 12.30% (11 100 lux), at 27 m, 5.49% (5 000 lux) and at 37 m, 0.29% (266 lux). This kind of analysis is possible on the rest of the data although complications arise due to varying water characteristics at the different stations, varying overhead conditions, and the inconsistencies mentioned above. The light profile just analysed gives an indication of the way light varied in the ocean in the Canterbury area.

1.4 d Otago area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

The Otago study area extended from Waitaki River mouth in the north (44°55'S), south to Tautuku Peninsula (46°37'S). However, all samples analysed during this study were collected from Blueskin Bay.

This area, like the Canterbury area, is also affected by the Southland Current and much of the discussion on this current in Section 1.4 c is relevant to the Otago area.

Recent studies on the hydrology and oceanic circulation in the Otago area were carried out by Jillett (1969) and Robertson (1973). Their studies provide excellent summaries of the hydrological situation in Otago waters.

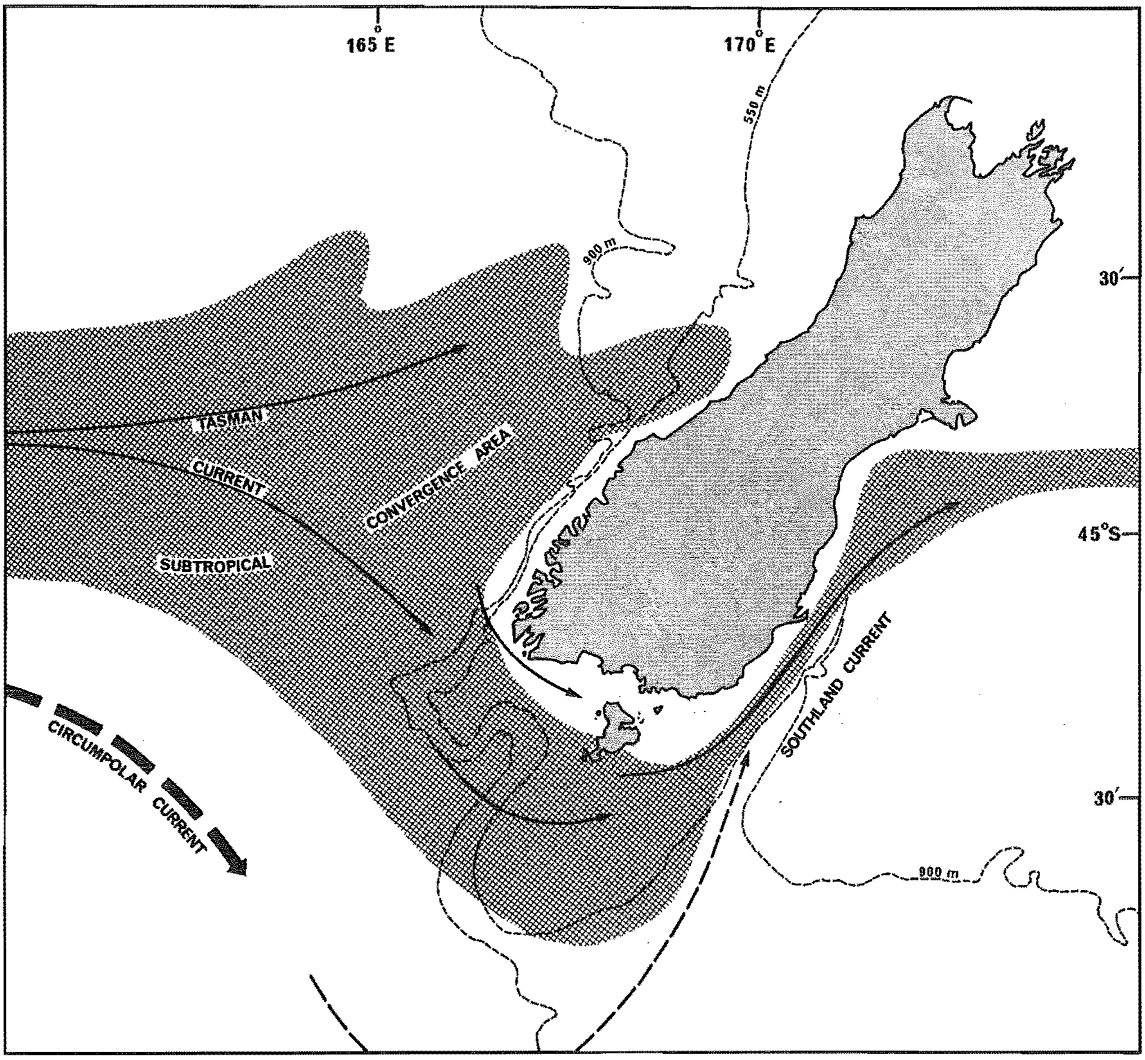
Fortuitously, Robertson's work partly overlapped with mine in terms of time. Therefore, many of his findings equally hold for this study.

Samples of red cod were collected from Blueskin Bay in May and November 1971, and February 1972. During November 1971 to February 1972, Robertson found that surface water temperature in this area rose from 13°C to 16°C. Bottom temperatures varied similarly. Salinities were low, being typically less than 34.6‰, for both surface and bottom waters.

The bathymetry of the Blueskin Bay is well figured by James (1970, p. 231).

FIGURE 7

Distribution of water-masses and currents near Foveaux Strait (after Houtman, 1966).



165° E
170° E
550 m
900 m
30′
45°S
30′
TASMAN
CURRENT
SUBTROPICAL
CONVERGENCE AREA
CIRCUMPOLAR CURRENT
SOUTHLAND CURRENT
900 m

1.4 e Foveaux Strait area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

This area extended from Tautuku Peninsula in the east (46°37'S, 169°25'E) to Puysegur Point in the west (46°09'S, 166°38'E).

One sample was taken from this area. This was from Te Waewae Bay (46°14'S, 167°31'E) in November 1971.

Various workers have discussed the hydrology and oceanic circulation in this area (Deacon 1937; Dell, 1952; Bary, 1959; Garner, 1959, 1961, 1967; Brodie, 1960; Burling, 1961; Starr, 1961; Garner and Ridgway, 1965; Houtman, 1966, 1967; Jillett, 1969; and Heath, 1971a, 1972, 1973).

As for both the Canterbury and Otago areas, the Southland Current is present in this area. It constitutes a warm and saline branch of the Tasman Current and flows eastwards through Foveaux Strait before it turns northwards to impinge upon the Otago area. Houtman's (1966) interpretation is presented in Figure 7.

1.4 f West Coast South Island (W.C.S.I.) area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

This area extended from Puysegur Point (See previous section), north to Cape Farewell (40°30.5'S, 172°42'E).

The oceanic circulation on the west coast of New Zealand is closely connected with that on the Australian east coast (Starr, 1961; Wyrtki, 1962; Heath, 1973).

The Tasman Current (See Fig. 5), which is derived from the East Australian Current, gives rise to the Westland Current on the one hand, this flowing northwards along the west coast of the South Island, and to the Southland Current on the other (See Fig. 7). Like the latter current, the Westland Current is also warm and saline although considerable dilution is possible due to river outflow (Garner, 1961).

Information on bathymetry, water temperature and salinity for this area is presented by Garner (1959), Garner and Ridgway (1965), Garner (1967), Stanton (1971), and Heath (1973).

Samples were taken from this area in March 1972. Water temperature (Fig. 8), and light intensity (Table 2), in relation to depth were recorded. Details of time of day, conditions and position for both sets of parameters are presented in Table 2.

FIGURE 8

Water temperature - depth profiles for the West Coast South Island area, March 1972 (For details of time, conditions, and position, see Table 2).

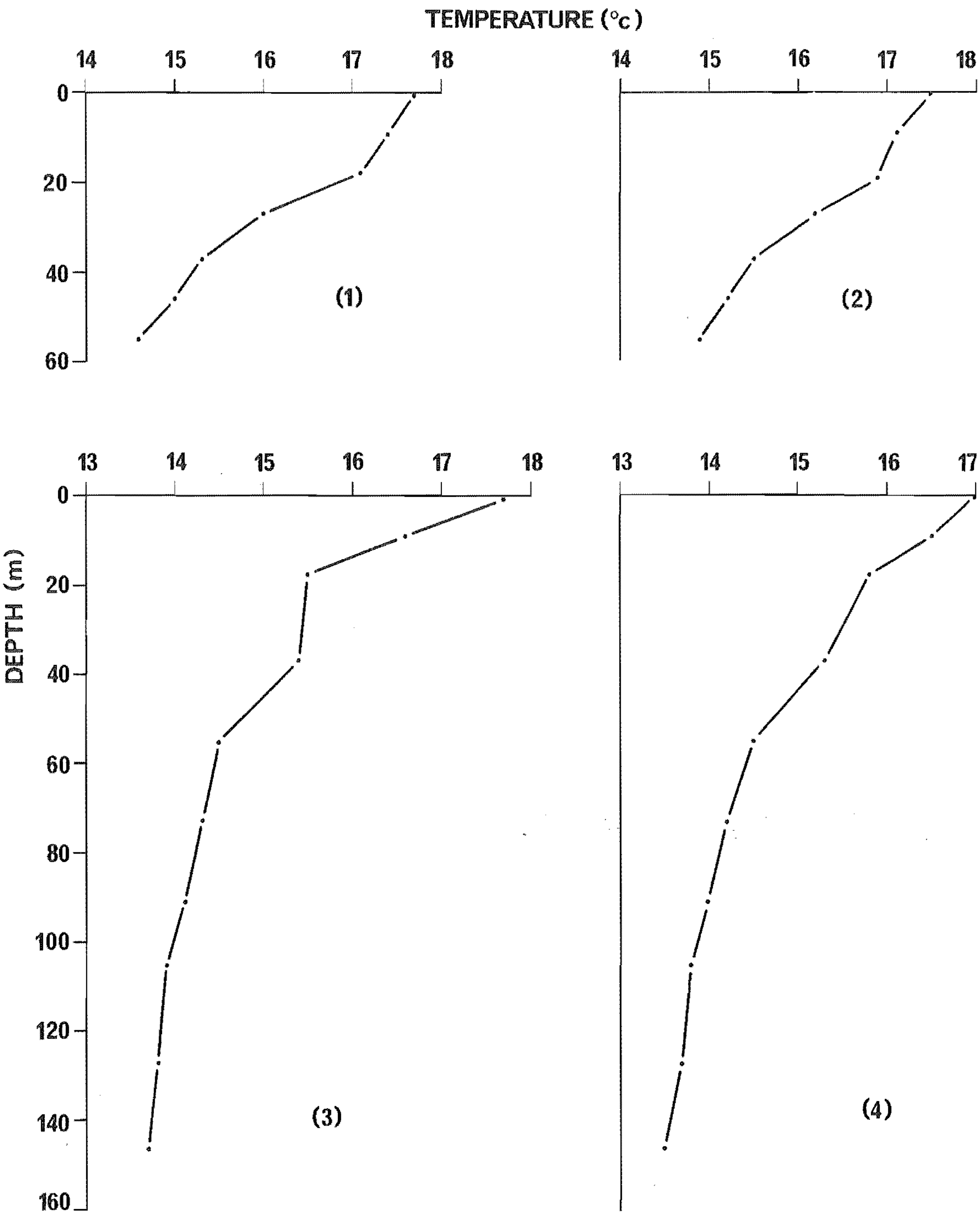

TEMPERATURE (°c)
DEPTH (m)
(1)
(2)
(3)
(4)

Table 2: Light intensity in relation to depth of water in the West Coast South Island area, March 1972.

Month, Time Conditions, Position	Depth (m)	Light (lux)	Month, Time Conditions, Position	Depth (m)	Light (lux)
Mar. 1972(1), 1720 h,	0	1 700	Mar. 1972(2), 1120 h,	0	1 860
overcast,	9	860	overcast,	9	1 285
42°20'S, 170°27'E	18	745	42°40'S, 170°55'E	18	1 145
	27	208		27	425
	37	113		37	157
	46	29		46	40
	55	17		55	4
Mar. 1972(3), 1710 h	0	1 700	Mar. 1972(4), 0820 h,	0	10 400
overcast,	9	600	partly overcast,	9	1 900
42°51'S, 170°07'E	18	325	43°13'S, 169°57'E	18	1 180
	37	67		37	260
	55	22		55	44
	73	12		73	12
	91	7		91	10
	110	6		110	10
	128	4		128	9
	146	2		146	4

The temperature profiles are similar in form to those found in this area by Garner (1969). There was a more or less steady decrease in water temperature with increasing depth. However, the surface temperatures found in this study were somewhat higher (17.0°-17.8°C c.f. Garner's 15.0°-16.0°C). These higher readings were possibly due to coastal dilution, evidence of which was present at the time recordings were made. Garner noted that such areas tend to be warmer than their surroundings. He also noted that in these areas, a shallow secondary thermocline is often present within the upper mixed layer, probably marking the depth of diluted water. This description may explain the 18 m - 15.5°C point in Figure 8(3).

Light intensity with depth was measured at four stations in this area (Table 2). At all stations, there were rapid decreases in light with depth increase. The readings at stations (1), (2), and (3) were directly comparable as the amount of surface light was very similar at these stations. And below 18 m depth, light was comparable at all four stations, despite there being about ten times more surface light at station (4) compared with the other stations.

Further analyses of the kind carried out in Section 1.4 c are

FIGURE 9

West Coast North Island water temperatures, September 1971.

(a) Sea surface temperatures.

(b) Bottom temperatures.

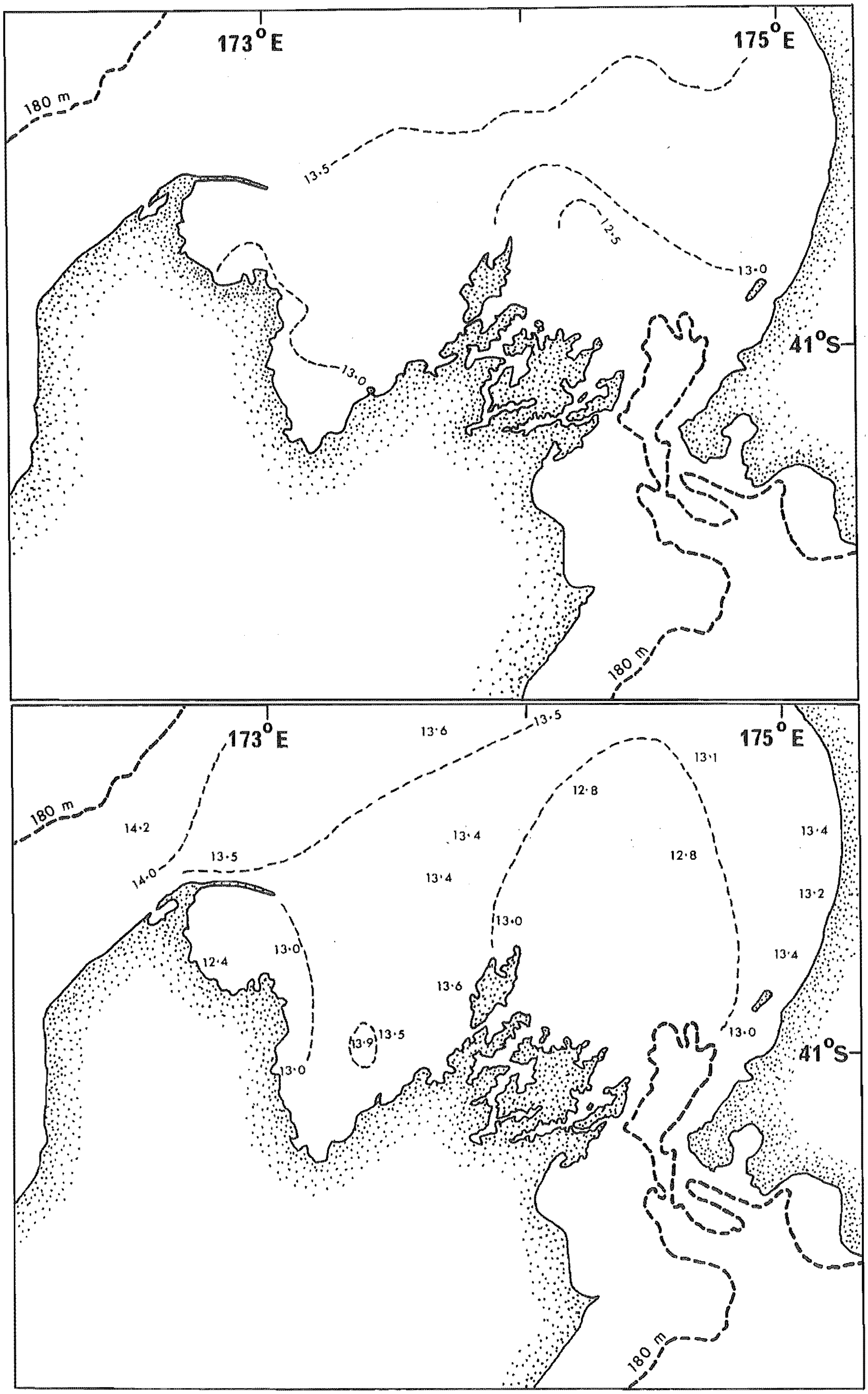
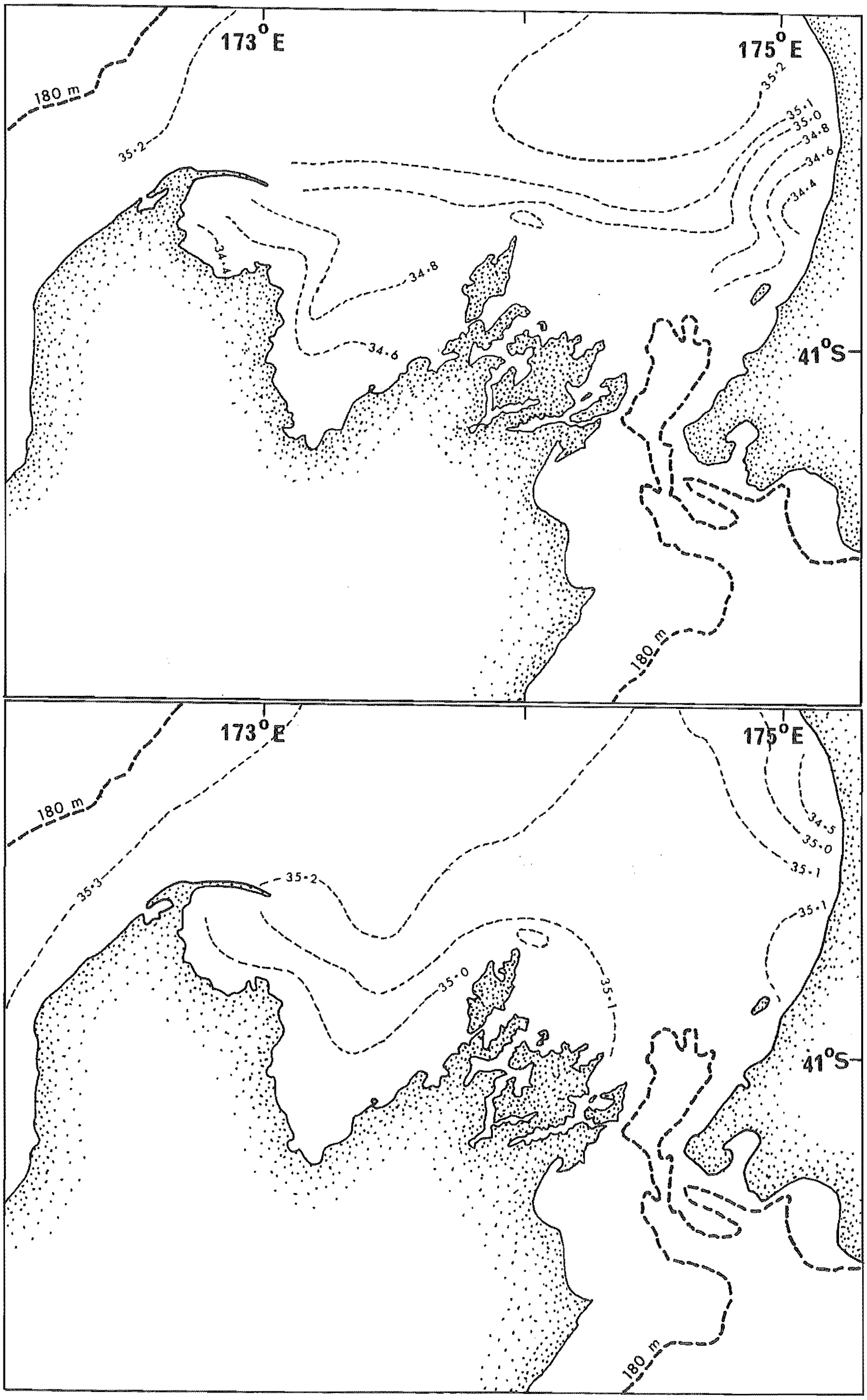

173°E
175°E
180 m
13·5
12·5
13·0
13·0
41°S
180 m
173°E
175°E
13·6
13·5
13·1
180 m
14·2
12·8
13·4
13·4
12·8
13·5
14·0
13·4
13·2
13·0
13·0
12·4
13·4
13·6
13·9
13·5
13·0
13·0
41°S
180 m

FIGURE 10

West Coast North Island salinities, September 1971.

(a) Sea surface salinities.

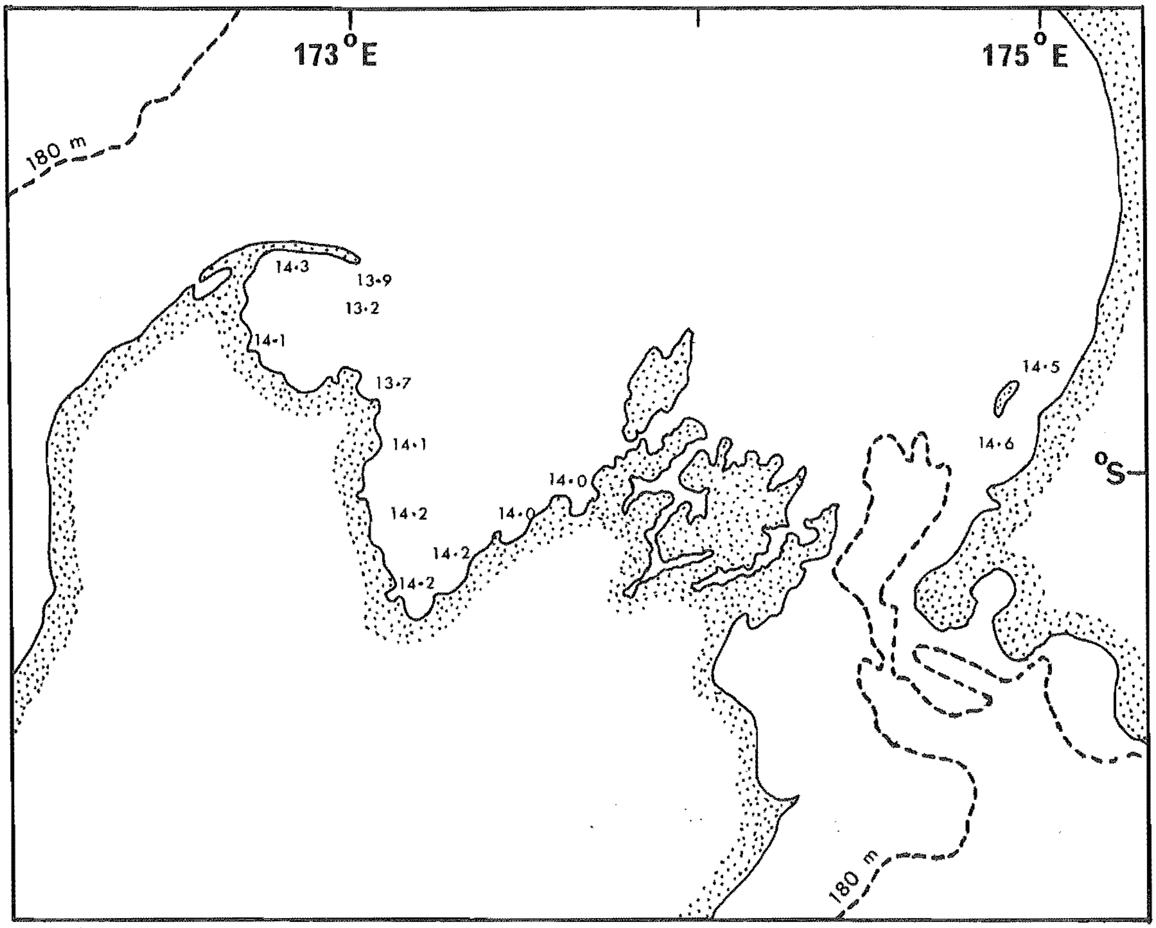
(b) Bottom salinities.



173°E
175°E
41°S
180 m
35·2
35·1
35·0
34·8
34·6
34·4
180 m
173°E
175°E
41°S
180 m
35·3
35·2
35·0
35·1
34·5
35·0
35·1
35·1
180 m

FIGURE 11

West Coast North Island sea surface temperatures, October 1973.



173°E
175°E
°S
180 m
180 m
14·3
13·9
13·2
14·1
13·7
14·1
14·0
14·2
14·0
14·2
14·2
14·5
14·6

possible on the data in Table 2.

1.4 g West Coast North Island (W.C.N.I.) area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

This area extended from Cape Farewell to the Rangitikei River mouth (40°17'S, 175°14'E), and south to include Wellington Harbour, the enclosed section of W.C.N.I., Tasman and Golden Bays.

The ocean current which affects this area is the D'Urville Current. Composed of warm saline Subtropical Water, it has its origin in the inshore component of the north flowing Westland Current (Brodie, 1960; Heath, 1969). Described by Brodie as a "... marked indraught into Cook Strait...", the path of the D'Urville Current is shown by Heath (1969, pp. 7-8). Heath also provides an excellent summary of the water movements in this area. The hydrology of this area was investigated by Garner (1959, 1961, 1969), and Stanton (1969). Their findings were very similar. They found an annual range in surface temperatures of about 5°C, with July minima (11.0° - 13.0°C), and maxima in January-February (16.0°-18.0°C).

Samples of red cod were obtained from this area in September and November 1971, and October 1973. Surface and bottom temperatures and salinities were measured during September (Figs. 9 and 10), and surface water temperatures only were measured in October (Fig. 11). No readings were taken during November.

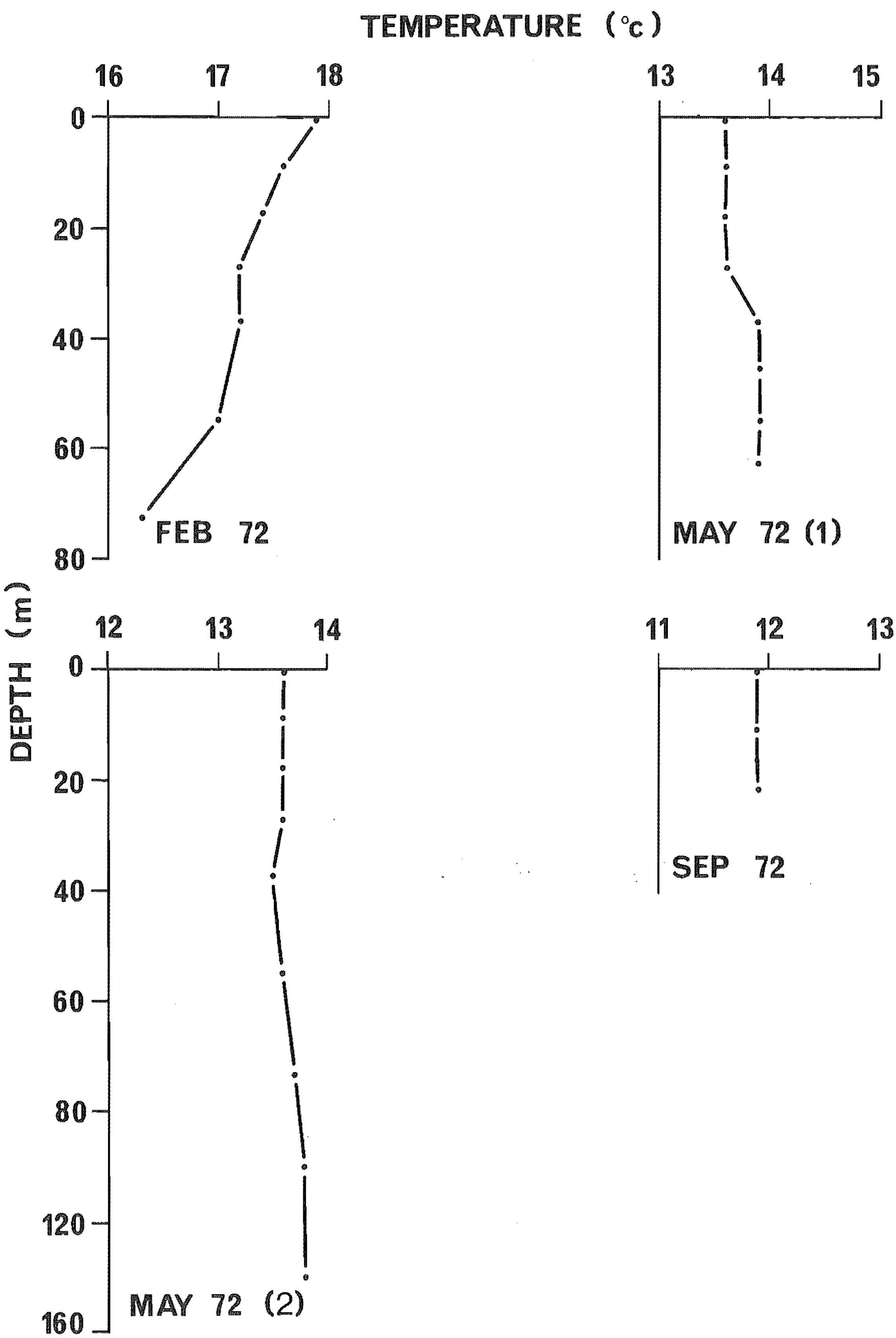
The September surface temperatures ranged from 12.5°-13.5°C in a more or less south to north progression across the study area. Bottom temperatures had a similar range and progressed similarly. This produced the essentially winter hydrological situation of an isothermal water column.

Salinities also showed a tendency to increase from south to north, with a superimposed tendency to increase from west to east across the study area (See Fig. 10). There were few differences between surface and bottom salinities, although surface waters in Golden and Tasman Bays were of lower salinity than in corresponding bottom waters.

The October 1973 surface temperature range of 13.2°-14.6°C was within the expected range.

FIGURE 12

Cloudy Bay - Cape Campbell water temperature with depth profiles for February 1972, May 1972(1), May 1972(2), and September 1972.



TEMPERATURE (°c)
DEPTH (m)
16
17
18
0
20
40
60
80
FEB 72
13
14
15
MAY 72 (1)
12
13
14
0
20
40
60
80
120
160
MAY 72 (2)
11
12
13
SEP 72

1.4 h Cloudy Bay - Cape Campbell (C.B.C.C.) area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

This area extended from Cape Palliser (41°36.5'S) on the east coast of the North Island, south to the Haumuri Bluffs (42°33'S), and north into Cook Strait to a line crossing the strait at 41°19'S.

The ocean waters in this area are derived from three sources. These are the north-flowing Southland Current (See Section 1.4 c, 1.4 d and 1.4 e), the D'Urville Current which flows south through Cook Strait (See Section 1.4 g), and the East Cape Current which flows down the east coast of the North Island. Heath (1973) describes their meeting thus: "The water of the Southland Current in Cook Strait mixes with water from the D"Urville Current flowing in from the north and water over the Cook Strait Canyon from the East Cape Current. Mixed water derived from all three currents travels eastward across Cook Strait and around Cape Palliser to meet the water of the Southland Current that has diverged seaward between Kaikoura and Cook Strait". Information on the hydrology of this area is presented by Garner (1953, 1959, 1961), and Heath (1971a, 1973). For example, Garner (1959), in analysing data collected in 1950, found an annual temperature range of 3.6°C at the surface. The minimum temperature was recorded in August (12°C), the maximum in February (15.6°C). In the same paper, he also presented evidence of the presence of a typical isothermal winter water column (his Fig. 6).

Samples of red cod were obtained from this area in February, May, and September, 1972. Water temperature and light intensity in relation to depth were recorded (Fig. 12 and Table 3). Details of month, time, conditions and position for both temperature and light stations are presented in Table 3.

The temperature profile for February showed a steady rate of decline with increasing depth, as is typical for summer. The winter profiles (May and September) however, were depicted by vertical lines indicating the typical isothermal water column of winter.

All light readings were taken on bright, sunny, or partly cloudy days, hence the high surface values. Light rapidly decreased in intensity with increasing depth. It is interesting that at 9 m depth, light intensity was about the same at all stations. It is clear too, that below about 45 m depth, there was very little light.

Table 3: Light intensity in relation to depth of water in the area Cloudy Bay-Cape Campbell, February 1972, May 1972(1), May 1972(2), and September 1972.

Month, Time, Conditions, Position	Depth (m)	Light (lux)	Month, Time, Conditions, Position	Depth (m)	Light (lux)
Feb. 1972, 1430 h, clear sunny, 41°32'S, 174°19'E	0	91 000	May 1972(1), 1430 h partly cloudy, 41°28.5'S, 174°17'E	0	15 800
	9	2 500		9	2 250
	18	285		18	675
	27	46		27	147
	37	26		37	24
	55	7		46	8
	73	4		55	5
				64	5
May 1972(2), 1515 h, partly cloudy, 41°27.5'S, 174°22'E	0	12 250	Sep. 1972, 1640 h, partly cloudy, 41°32'S, 174°12'E	0	30 000
	9	2 450		4	12 250
	18	780		7	2 500
	27	172		11	1 660
	37	16		15	1 232
	55	5		18	625
	73	5		22	183
	91	5			
	101	5			
	110	4			

1.4 i East Cape area, its hydrology and oceanic circulation (See Fig. 4 and Fig. 5)

This area extended north from Cape Palliser, around East Cape to latitude 37°25'S, and east to a line which runs north-east from the Whakatane River mouth (37°57'S, 177°00'E), through to White Island (37°32'S, 177°11'E) in the Bay of Plenty.

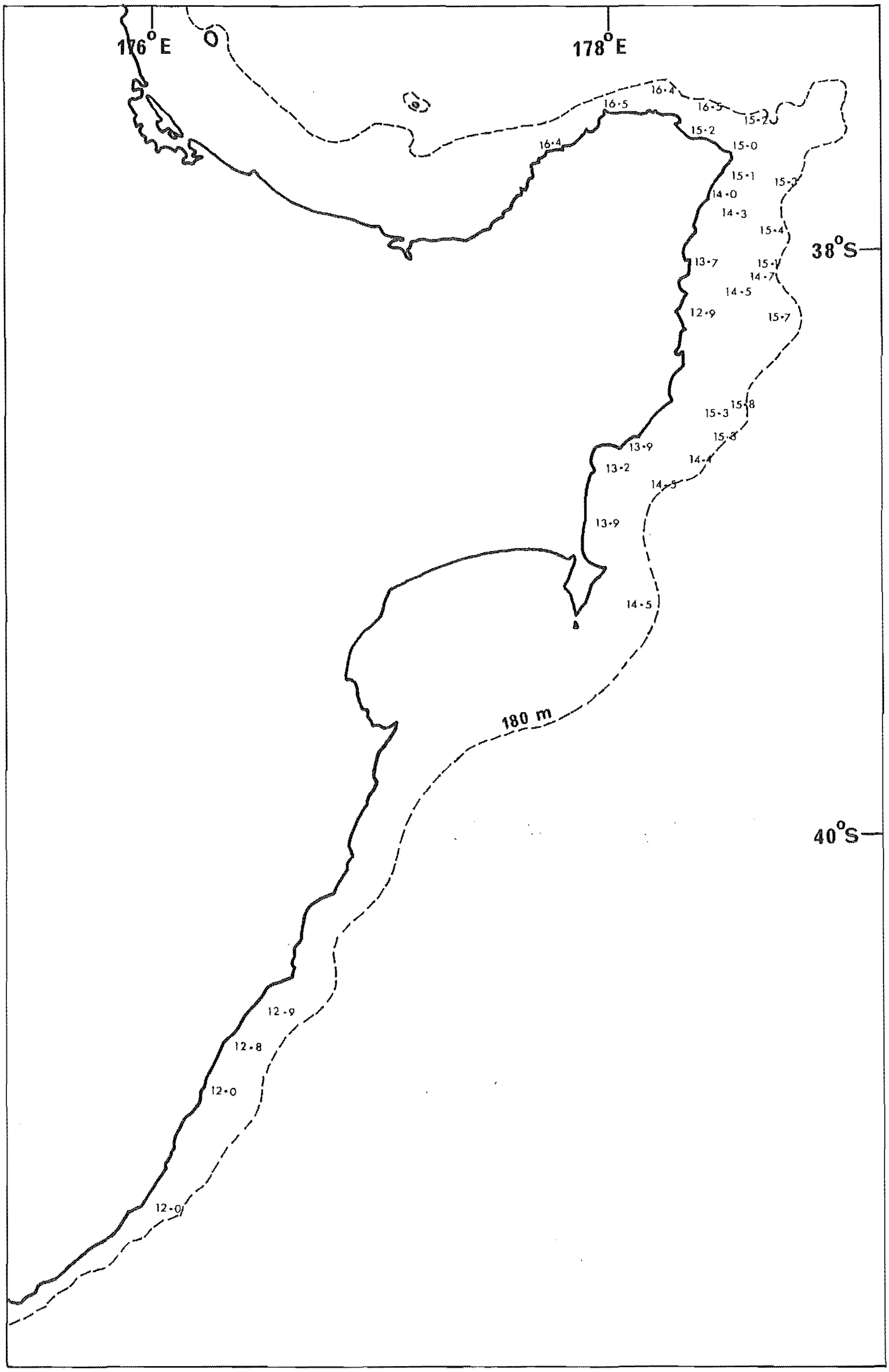
The East Cape Current affects this area. Having its origin in the East Auckland Current, which in turn is derived from the Tasman Current, the East Cape Current is a warm saline body of water (18°-21°C, 35.2 -35.5‰ salinity at the surface in summer according to Heath, 1973), which flows southward through the East Cape study area (Heath, 1971a).

Considerable hydrological information is to be found in the literature on this area, by such workers as Garner (1959, 1961, 1969), Garner and Ridgway (1965), and Heath (1971a, 1973).

A sampling trip was made to this area in July 1973. Surface temperatures were recorded at all sampling stations. These are

FIGURE 13

East Cape study area surface temperatures, July 1973.



176°E
178°E
38°S
40°S
180 m
16·4
16·5
16·4
16·5
15·2
15·2
15·0
15·1
15·3
14·0
14·3
15·4
13·7
14·7
14·5
12·9
15·7
15·8
15·3
15·8
13·9
14·4
13·2
14·5
13·9
14·5
12·9
12·8
12·0
12·0

presented in Figure 13.

There was a steady decline in water temperature from the northernmost stations (East of White Island - 16.4°C), through the intermediate stations (East Cape - 15.3°C; Mahia Peninsula - 13.9°C), to the southernmost station (Castle Point - 12.0°C). A similar decline was detected by Garner (1969) in his analysis of temperature data for August-September 1967. For the same reference locations listed above, his findings were 14.5°C, 13.5°C, 13.5°C, and 11.5°C.

Garner also found that the water column at any particular station during winter was isothermal. The situation was probably little different in July 1973.

1.5 The sampling programme

1.5 a Introduction

During the period May 1971 - October 1973, samples of red cod (8 131 fish) were taken from the study areas as follows: Canterbury (4 384), Otago (403), Foveaux Strait (142), W.C.S.I. (227), W.C.N.I. (2 019), C.B.C.C. (905), and East Cape (51). All samples were collected by bottom trawl and taken back to the laboratory for analysis. From these samples, sub-samples were taken for full processing as follows: Canterbury (2 294), Otago (258), Foveaux Strait (122), W.C.S.I. (210), W.C.N.I. (203), C.B.C.C. (219), and East Cape (51). All fish were used in length frequency analyses (Section 3). Samples were also taken for meristic analyses (Section 2).

The main sampling was carried out in the Canterbury area during the period October 1971 - October 1972. Regular monthly samples were taken in the hope that dissection and monitoring of weights and measurements of red cod and their internal organs would yield information on the annual cycle of change in this species. It was also hoped that this information, together with hydrological information and catch data, would enhance understanding of the red cod's life history in relation to its environment.

When opportunity allowed, samples were taken from the other areas for comparison with the Canterbury samples, and with each other.

1.5 b Catch processing

At the laboratory, fish which had been set aside for full processing were measured to the nearest millimetre for total length (from the tip of the snout to the end of the caudal fin). Both whole and gutted weights to the nearest gram were then recorded after the fish were carefully blotted (Cala, 1971; Cadwallader, 1974). The removed internal organs (alimentary tract, gonads, liver) were also blotted, weighed and then further processed (For details, see Sections 5 and 6). Otoliths and scales were also collected for ageing studies. Unfortunately, there was no time for this during the study.

At the time of processing, fish were either in what Laevastu (1965, p. 13) referred to as "... the fresh, wet condition...", or preserved in about 10% formalin. It has been established that preservation can alter the length and weight of fish from the fresh condition (Lux, 1960; Parker, 1963; Cala, 1971; Staples, 1971; Cadwallader, 1974) although the manner and degree of alteration varies from one situation to another. Typically there is a decrease in length while weight can either increase or decrease.

The effect of formalin was determined from a sample of 50 fish which had been preserved in 10% formalin for one year. Both length and weight decreased with little variation over the size range of fish in the sample. The relationships were:

$$\text{Fresh length} = 1.007 \text{ Preserved length}$$

$$\text{Fresh weight} = 1.017 \text{ Preserved weight}$$

All analyses on preserved specimens took these correction factors into account.

1.5 c The catching methods

Many fishing trawlers were used to obtain samples and these employed a variety of sizes of trawl gear. Details are presented in Table 4.

Owing to the limited - finance structure of this study, I had to obtain my samples as best I could. The aim was to obtain as representative a sample of red cod from any one area as possible using what Lagler (1968) described as "available" gear. This frequently meant relying on the goodwill of fishermen to collect samples. On other occasions it meant the passive accompanying of commercial trawlers to their fishing grounds and sampling their catches. At these times, I exercised no control over the type of fishing gear used

Table 4: Fishing vessels and their gear used in this study.

Vessels	Port	Overall length (m)	Registered length (m)	Gross tonnage	Net type	Length ground rope (m)	Length extensions (m)	Effective codend mesh (cm)
James Cook (JC)	Nelson	42.1	-	552.8	Granton	36.6	73.2	2.5
W.J. Scott (WJS)	Nelson	28.4	26.1	167.0	Wing	27.4	-	2.5 - 3.8
Tirohia (Ti)	Wellington	13.3	12.0	23.0	Otter	15.3	-	2.5
Munida (Mu)	Port Chalmers	15.0	14.0	32.0	Vigneron-Dahl	15.3	-	1.9
Snark (Sn)	Lyttelton	-	14.4	26.3	Granton	24.0	91.0	10.2
Theseus (Th)	Lyttelton	-	13.0	14.6	Wing	18.0	69.0	10.2
Kestrel (Ke)	Lyttelton	-	12.4	22.0	-	-	-	10.2
Nimbus (N)	Lyttelton	-	13.4	21.8	Granton	24.0	73.0	10.2
Marewa (M)	Lyttelton	-	13.9	20.2	Wing	24.0	55.0	10.2
Triena (T)	Lyttelton	-	14.9	30.5	Wing	27.0	55.0	10.2
Konini (Ko)	Lyttelton	-	-	-	Otter	12.2	29.5	6.4
Kingfisher (Ki)	Lyttelton	-	14.7	31.1	Wing	24.0	55.0	10.2
Anita (An)	Akaroa	-	11.3	-	Wing	20.1	-	11.4
Kotare (K)	Lyttelton	-	13.3	18.8	Wing	-	-	10.2
Cavalier (C)	Lyttelton	-	13.1	21.7	Granton	-	-	10.2
Narova (Na)	Lyttelton	-	10.4	7.5	Otter	1	1	10.2

or area fished, or any other part of the fishing operation. Consequently, much fishing was carried out in areas in which red cod were absent, thus wasting valuable time. This, together with the fact that the red cod fishery was in a period of decline during 1971-72 (See Section 3) made sample deadlines difficult to meet. Fish had then to be accepted from all possible sources to make up samples, an undesirable, but unavoidable, practice. The vessels involved in this phase of sampling are listed in Table 4, following "Munida" (All are commercial trawlers, in Figs in Section 4, abbreviated to CT).

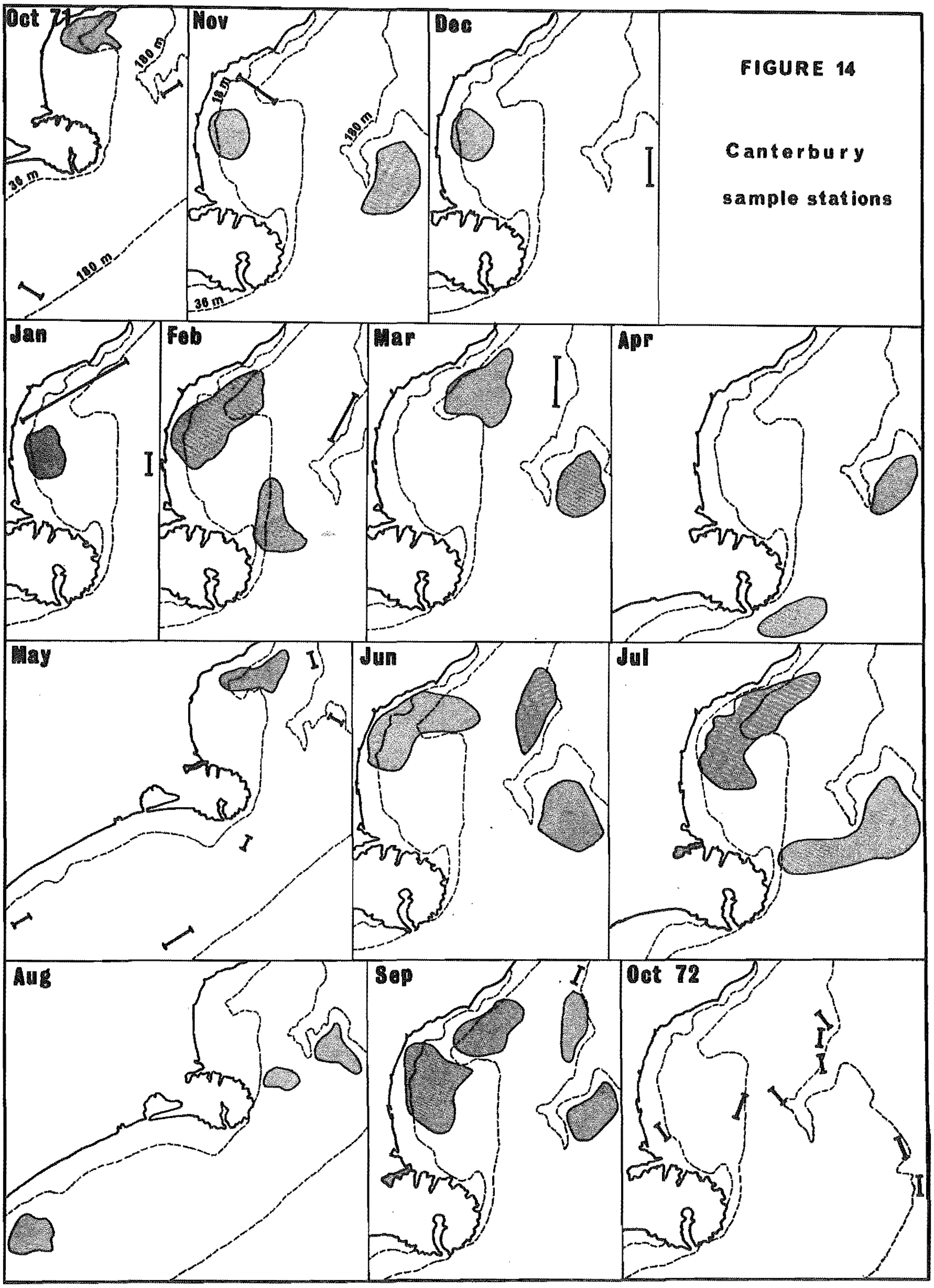
On yet other occasions, samples were obtained using the research vessels "James Cook", "W.J. Scott", "Tirohia" and "Munida" (Table 4). On these occasions, I did have some control over the fishing operation. With some prior knowledge of the red cod's biology and ecology, particular areas were sampled at particular times using particular fishing gear.

There was thus considerable variability in catching methods which affected the degree of representation which could be attributed to many of the samples taken.

An investigation of the selectivity of the various fishing gear used was not feasible. Selectivity, which may be defined by a curve giving, for each size of fish, the proportion of the total population of that size which is caught and retained by a unit operation of the gear, may result from extrinsic or intrinsic factors. The extrinsic include such factors as gear construction and the methods of operation, while the many features pertinent to the red cod, such as its behaviour, sex, size, habits and others, in relation to time of day, season, and area would constitute intrinsic factors. It is probable that many intrinsic and extrinsic factors operated in this study to impose a selectivity on many of the samples taken.

1.5 d Results - Catch data

Catch data for the various areas are presented in a series of tables (See Tables 5-11). In the tables, date, time trawled, area trawled, and speed of trawling by the vessels are presented, together with depth and water temperature at each sampling station. Catch of red cod is also listed, and an estimate of catch-effort may be gained by relating catch size to time trawled. From the catches made, red cod were taken for analysis.



Oct 71
180 m
36 m
180 m
Nov
18 m
180 m
36 m
Dec
FIGURE 14
Canterbury
sample stations
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct 72

Table 5: Catch data for the Canterbury area (* = Approx.).

Station number	Date	Time trawled	Latitude or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessels (for key to symbols see Table 4)
J14/001/71	13.10.71	1555-1655	43°27'-43°25'S,	173°34'-173°39'E	124	3.8	10.5	1.60	JC
J14/002/71	14.10.71	0515-0715	44°34'-44°38'S,	172°40'-172°31'E	428	3.8	10.4	1 275.00	JC
	24.10.71	18.00 h	Pegasus Bay - Inshore		18-37	3.0	10.6	41.00	Sn
	Oct. 1971	unknown	Pegasus Bay - Inshore		18-40	2.7-3.0	10.6	unknown	M, Th, N, K
	28-29.11.71	30.50 h	43°10'-43°15'S,	172°55'-173°05'E	18-40	3.0	14.5	38.77	Sn
	Nov. 1971	unknown	43°35'S *	173°35'E	106	3.0	14.3	70.00	Sn
	Nov. 1971		Pegasus Bay - In- and Offshore		18-183	3.6-3.0	14.4	unknown	M, T, Th
	15.12.71	18.00 h	43°24'-43°31'S,	173°42'-173°42'E	84-102	2.9	17.5	14.25	T
	18-20.12.71	45.00 h	43°22'S *	172°50'E	18-30	2.9	18.2	12.00	Sn
	24.1.72	18.00 h	43°03'-43°15'S,	172°45'-173°14'E	18-45	2.9	16.4	57.67	Sn
	27.1.72	20.00 h	"	"	18-45	2.9	16.3	97.70	Sn
J2/034/72	29.1.72	0925-1055	43°20'-43°25'S,	173°21'-173°21'E	68	3.8	15.4	1.64	JC
	24.1.72		Pegasus Bay - Inshore		18-45	2.9	-	0.62	T

Table 5: Continued

Station number	Date	Time trawled	Latitude or Area trawled		Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessels (for key to symbols see Table 4)
	6.2.72	6.75 h	43°12'E	*	173°35'E	146-172	3.0	-	26.99	Sn
	23.2.72	4.75 h	43°38'S	*	173°13'E	64-82	3.0	18.5	93.13	Sn
	23.3.72	3.50 h	43°25'S	*	173°13'E	33-42	3.0		34.87	Sn
	Feb. 1972	unknown	Pegasus Bay - Inshore			10-35	2.7-3.0	-	3.60	Th, Ke, M, N
	27-29.3.72	29.25 h	43°27'S	*	173°38'E	91-146	3.0	-	62.70	Sn
	25-26.3.72	unknown	43°03'-43°10'S,		173°34'-173°38'E	110-183	2.9	-	137.97	Ki, T
	Mar. 1972	unknown	Pegasus Bay - Inshore			30-40	2.9	-	3.61	T
	Mar. 1972	3.50 h	43°07'-43°10'S,		173°35'-173°38'E	110-183	3.0	-	9 262.00*	Ki
	14-15.4.72	17.00 h	43°27'S	*	173°38'E	91-146	3.0		34.11	Sn
	17-18.4.72		43°27'S	*	173°38'E				38.40	T, N
	22.4.72	6.00 h	43°55'-43°56'S,		172°59'-172°36'E	51-53	2.4		1 319.94	An
	26.5.72	4.00 h	Lyttelton Harbour			3-7	2.0	12.5	6.01	Ko
	19-20.5.72	18.00 h	43°03'-43°10'S,		173°03'-173°14'E	40-48	3.0	13.0	303.91	Sn
J7/014/72	11.5.72	1807-1907	43°02'-43°05'S,		173°37'-173°38'E	146	4.0	13.0	7.03	JC
J7/016/72	12.5.72	0542-0742	44°34'-44°37'S,		172°39'-172°32'E	209-228	3.0	11.7	12.34	JC
J7/025/72	14.5.72	0500-0650	43°20'-43°22'S,		173°38'-173°44'E	124	3.8	13.0	4.75	JC
J7/024/72	13.5.72	2025-2125	44°05'-44°02'S,		173°09'-173°11'E	82	4.0	9.0	0.31	JC
	20.5.72	unknown	Pegasus Bay - Inshore			18-36	2.9	-	2.57	N

Table 5: Continued

Station number	Date	Time trawled	Latitude	or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel (for key to symbols (see Table 4)
	6.6.72	unknown	43°08'S	*	173°36'E	120-140	2.9	-	146.62	Ki
	7.6.72	unknown	43°10'S	*	173°38'E	120-140	3.0	-	39.80	T
	12.6.72	unknown		Pegasus Bay - Inshore		18-40	2.8	-	0.13	N
	19.6.72	14.00 h	43°34'-43°35'S,		173°34'-173°47'E	86-110	3.0	13.0	390.39	Sn
	3.7.72	5.00 h	43°28'S	*	173°07'E	29	3.0	12.3	25.35	Sn
	3.7.72	5.00 h	43°30'S	*	173°08'E	30	3.0	12.3	4.31	Sn
	3.7.72	5.00 h	43°34'S	*	173°34'E	82-110	3.0	-	13.58	Sn
	4.7.72	5.00 h	43°35'S	*	173°34'E	82-110	3.0	-	385.90	Sn
	7.7.72	14.00 h	43°35'S	*	173°34'E	82-110	3.0	-	192.95	Sn
	Jul. 1972	unknown		Pegasus Bay - Inshore		15-40	2.4	-	2.60	Th
	18.7.72	5.00 h		Lyttelton Harbour		3-7	2.0	13.3	7.37	Ko
	21.7.72	16.00 h	43°12'-43°15'S,		173°04'-173°07'E	27-46	3.0	12.2	68.41	Sn
	Jul. 1972	unknown		Pegasus Bay - Inshore		15-40	2.7-3.0	-	3.06	Th, C, K, N
	10.8.72	12.00 h	43°41'S	*	173°14'E	64-69	3.0	10.0	2.69	Sn
	11.8.72	16.50 h	43°35'S	*	173°34'E	82-110	3.0	10.8	63.92	Sn
	16.8.72	30.00 h	43°34'S	*	173°34'E	82-110	3.0	10.5	72.22	Sn
	Aug. 1972	unknown		Canterbury Bight - Offshore		-	-	-	25.62	WJS
	Aug. 1972			Pegasus Bay - Inshore		18-40	2.7-3.0	10.4	unknown	T, Ko, M, C

Table 5: Continued

Station Number	Date	Time trawled	Latitude or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel (for key to symbols see Table 4)
	9.9.72	5.00 h	Lyttelton Harbour		2-7	2.0	12.2	4.0	Ko, Na
	18.9.72	8.00 h	43°07'-43°10'S,	173°35'-173°38'E	110-183	2.9	-	154.36	Ki
	26-27.9.72	22.50 h	43°12'-43°16'S,	172°48'-173°07'E	9-46	3.0	-	1.99	Sn
	28.9.72	6.50 h	43°07'S *	173°35'E	110-201	3.0	12.0	21.54	Sn
J13/020/72	28.9.72	1042-1125	42°59'-42°57'S,	173°36'-173°35'E	117-121	3.8	9.3	1.25	JC
	Sep. 1972	unknown	Pegasus Bay - In- and Offshore		15-183	2.7-3.0	-	unknown	K, Ko, N, M
	15.10.72	unknown	43°07'-43°10'S,	173°35'-173°38'E	110-183	2.9	-	34.09	Ki
J15/001/72	28.10.72	1225-1325	43°27'-43°23'S,	173°13'-173°12'E	33-35	4.0	-	0.22	JC
J15/002/72	28.10.72	1445-1510	43°22'-43°24'S,	173°21'-173°22'E	73-76	3.5	-	1.16	JC
J15/003/72	28.10.72	1710-1720	43°14'-43°14'S,	173°34'-173°35'E	146-219	3.8	-	5.92	JC
J15/004/72	28.10.72	1800-1900	43°11'-43°07'S,	173°35'-173°36'E	120-130	3.8	-	447.35	JC
J15/005/72	29.10.72	0635-0735	43°31'-43°35'S,	173°56'-173°59'E	137-165	4.0	-	1.72	JC
J15/007/72	29.10.72	1216-1316	43°40'-43°43'S,	174°02'-174°02'E	320-358	3.5	-	2.16	JC
J15/011/72	30.10.72	0922-1022	43°29'-43°29'S,	172°47'-172°49'E	18-19	4.0		2.25	JC

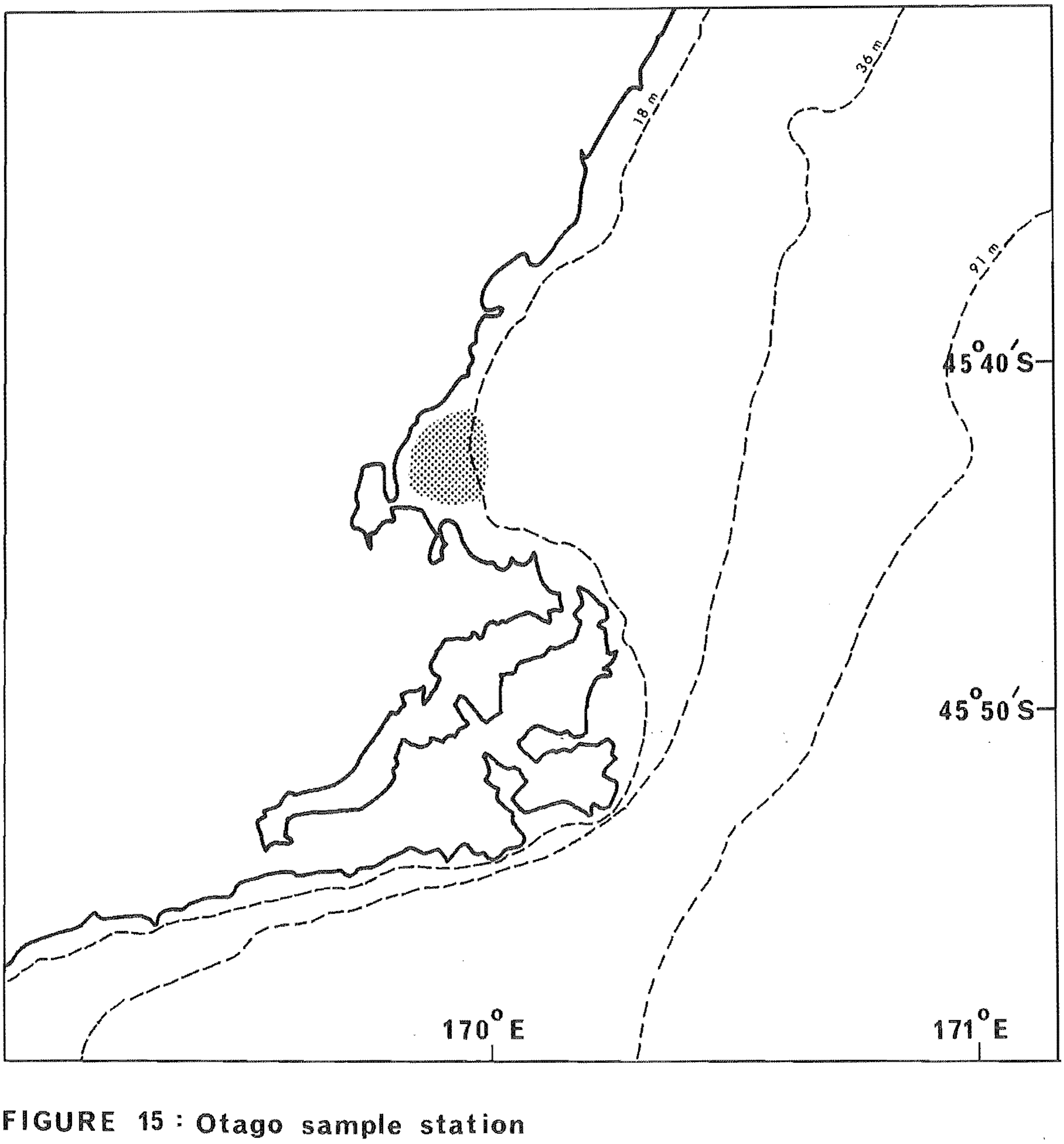


FIGURE 15 : Otago sample station

Table 6: Catch data for the Otago area (* = Approx.).

Date	Time trawled	Latitude or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel
18.5.71	2.50 h	Blueskin Bay - Otago		17	2.0	12.5	17.43	Munida
19.5.71	1.50 h	Blueskin Bay - Otago		12-18	2.0	12.5	54.03	Munida
21.5.71	1.50 h	Blueskin Bay - Otago		12-18	2.0	12.5	116.78	Munida
Nov. 1971	unknown	Blueskin Bay - Otago		12-18	-	-	326.88	W.J. Scott
14.2.72	0940-1040	45°43'-45°42'S,	170°42'-170°39'E	20-26	-	-	0.87	Munida
14.2.72	1125-1210	45°45'S	170°38'E	13-15	-	-	0.58	Munida

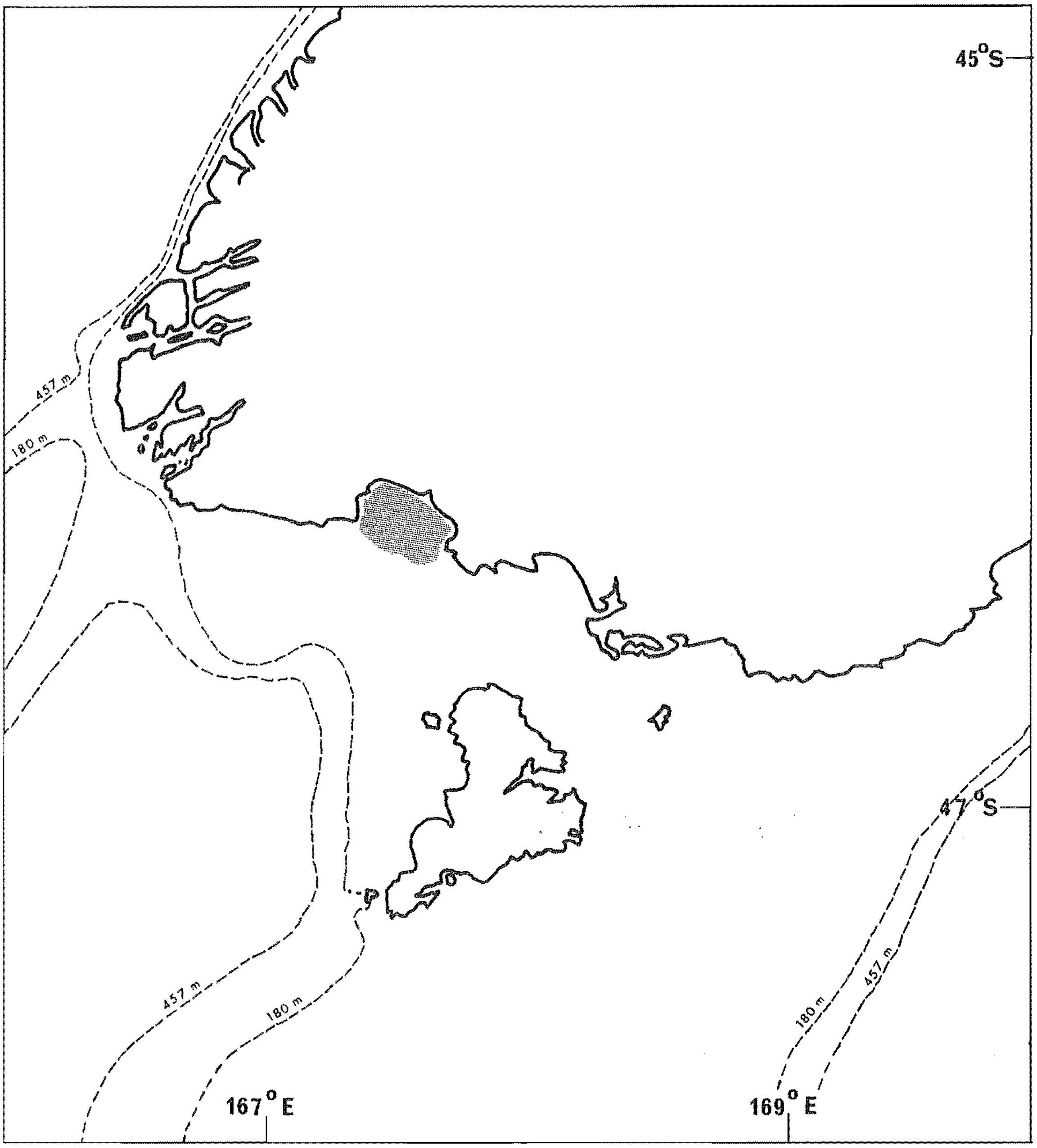


FIGURE 16 : Foveaux Strait sample station

Table 7: Catch data for the Foveaux Strait area (* = Approx.)

Date	Time trawled	Area trawled	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel
Nov. 1971	*4 days	Te Waewae Bay, Foveaux Strait	9-26	-	-	230.21	W.J. Scott

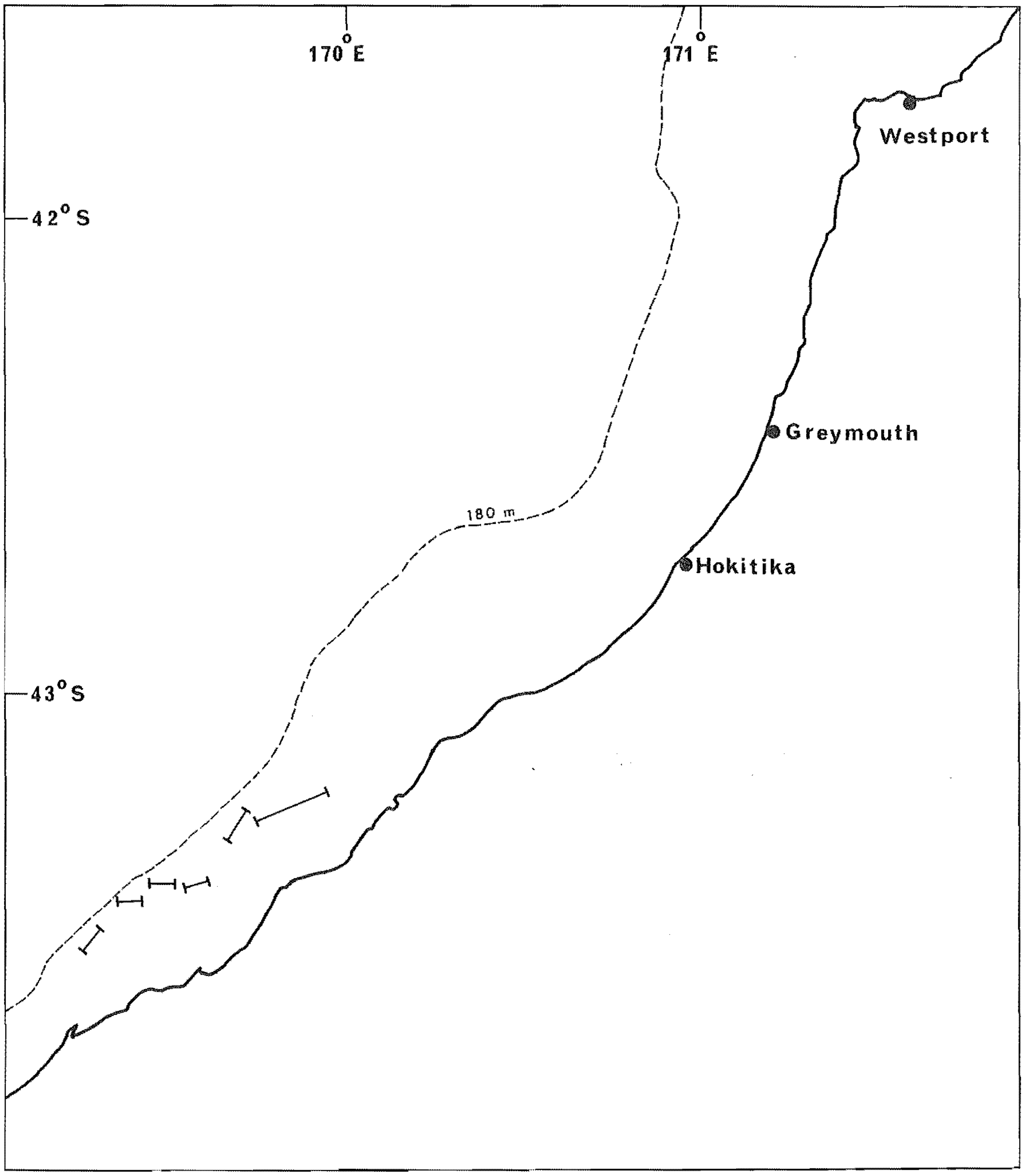


FIGURE 17 : W.C.S.I. sample stations

Table 8: Catch data for the W.C.S.I. area

Station number	Date	Time trawled	Latitude or Area Trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (C)	Red cod caught (kg)	Vessel
J4/005/72	10.3.72	1342-1442	42°43'-42°45'S,	170°23'-170°19'E	101-113	4.2	18.0	1.14	James Cook
J4/006/72	10.3.72	1602-1702	42°55'-42°51'S,	170°09'-170°07'E	146	4.3	17.8	0.90	"
J4/009/72	11.3.72	1140-1240	43°32'-43°29'S,	169°15'-169°18'E	142	3.7	18.0	3.62	"
J4/010/72	11.3.72	1347-1447	43°27'-43°26'S,	169°20'-169°24'E	128-139	3.7	18.1	4.46	"
J4/011/72	11.3.72	1547-1647	43°24'-43°24'S,	169°27'-169°32'E	146-149	3.3	18.1	13.38	"
J4/013/72	12.3.72	0715-0815	43°16'-43°13'S,	169°53'-169°57'E	137-146	3.8	17.0	13.78	"
J4/014/72	12.3.72	1005-1105	43°15'-43°19'S,	169°58'-169°56'E	46-67	3.7	16.8	5.65	"
J4/015/72	12.3.72	1436-1536	43°24'-43°24'S,	169°30'-169°26'E	124-128	3.2	18.1	6.07	"

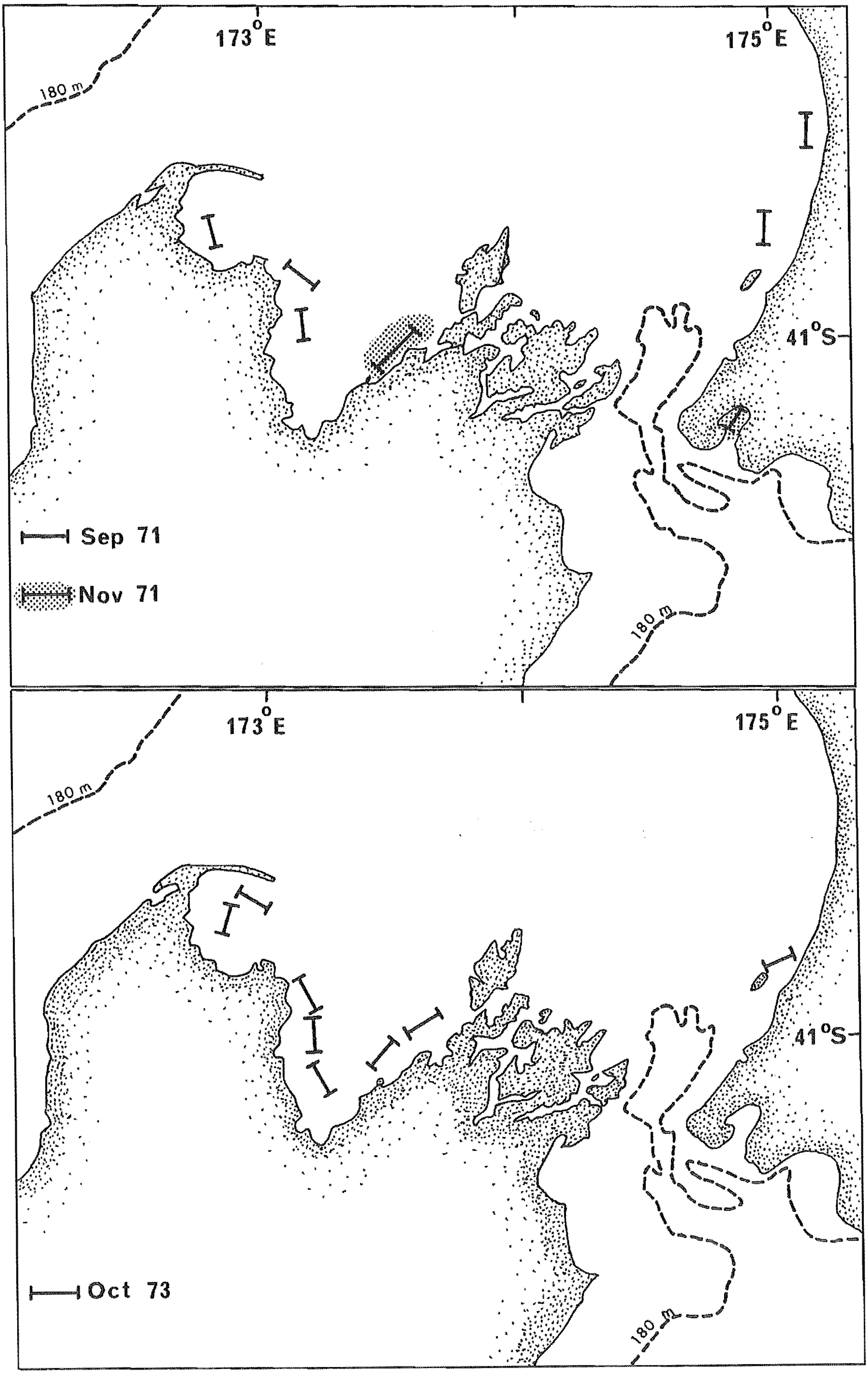


FIGURE 18: W.C.N.I. sample stations

Table 9: Catch data for the W.C.N.I. area (* = Approx.)

Station number	Date	Time trawled	Latitude or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel
J12/001/71	13.9.71	1225-1325	41°00'-40°57'S,	173°06'-173°06'E	20-27	3.3	12.9	2.29	James Cook
J12/003/71	13.9.71	1415-1515	40°50'-40°48'S,	173°08'-173°05'E	35-36	3.7	12.6	2.96	"
J12/005/71	13.9.71	1703-1803	40°41'-40°44'S,	172°46'-172°47'E	17-18	3.7	12.7	0.39	"
J12/018/71	15.9.71	0828-0928	40°43'-40°40'S,	175°00'-175°03'E	61-64	3.9	12.2	0.23	"
J12/022/71	15.9.71	1230-1330	40°23'-40°20'S,	175°11'-175°11'E	18-20	3.5	12.3	0.12	"
	Sep.1971	unknown	Wellington Harbour		-	-	-	10.88	Tirohia
	Nov.1971	10.00 h	Tasman Bay - off Croixelles Hbr.		*46	-	-	3 632.00	W.J.Scott
J16/084/73	22.10.73	1126-1226	40°49'-40°48'S,	175°00'-175°02'E	34	3.0	14.5	17.21	James Cook
J16/087/73	23.10.73	0610-1710	40°58'-41°02'S,	173°37'-173°33'E	41-44	3.5	14.0	4.27	"
J16/088/73	23.10.73	0748-0848	41°03'-41°05'S,	173°29'-173°27'E	31-36	3.2	14.0	3.18	"
J16/090/73	23.10.73	1147-1247	41°05'-41°03'S,	173°11'-173°09'E	25-26	3.0	14.2	4.96	"
J16/091/73	23.10.73	1326-1426	41°00'-40°56'S,	173°07'-173°07'E	24	3.7	14.1	6.49	"
J16/092/73	24.10.73	0934-1034	40°50'-40°48'S,	173°07'-173°04'E	34-36	3.0	13.7	25.42	"
J16/094/73	24.10.73	1250-1350	40°39'-40°38'S,	173°02'-172°57'E	34	3.0	13.9	10.89	"
J16/095/73	24.10.73	1416-1516	40°39'-40°42'S,	172°54'-172°52'E	27	3.0	14.3	4.59	"

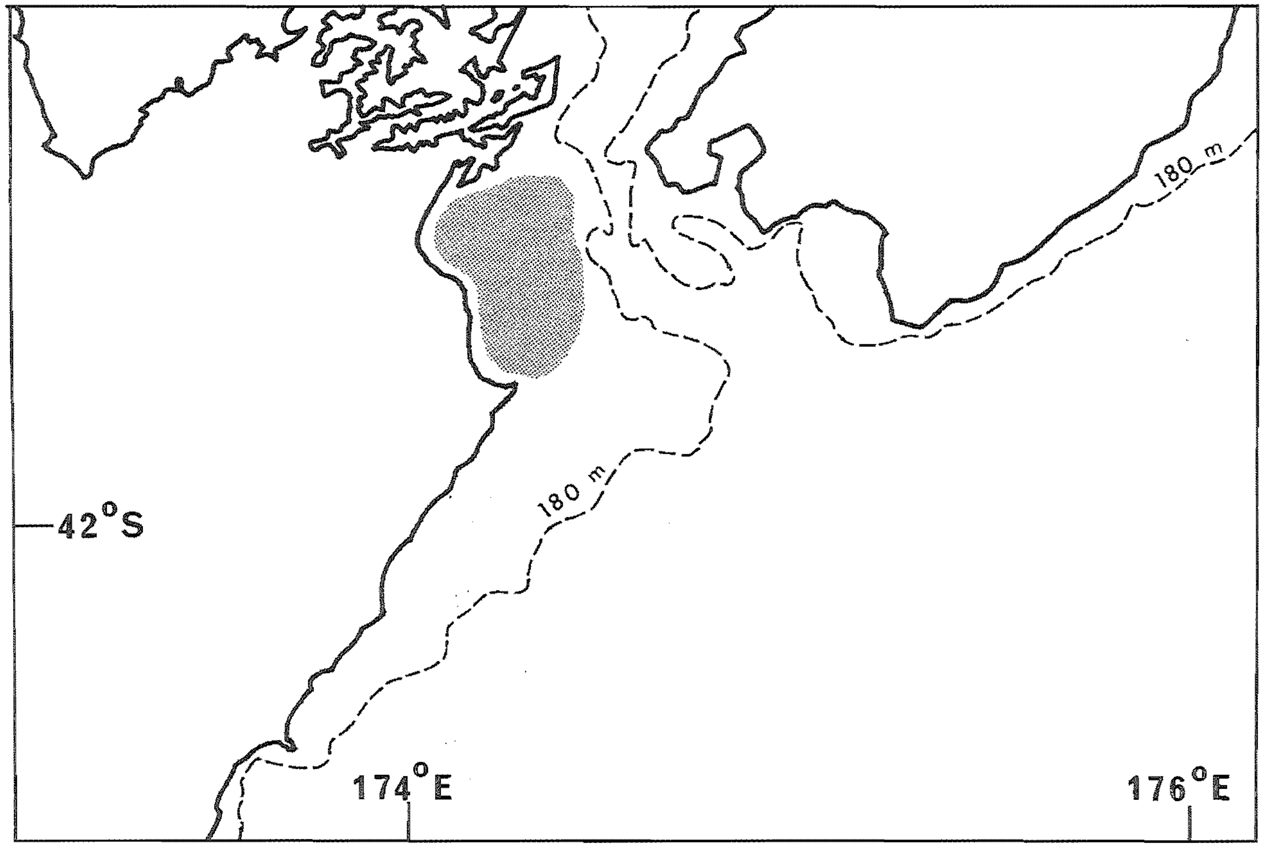


FIGURE 19: C.B.C.C. sample station

Table 10: Catch data for the C.B.C.C. area

Station number	Date	Time trawled	Latitude (or Area trawled)	Longitude (or Area trawled)	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel
	2-5.2.72	49.75 h	41°23'-41°32'S,	174°03-174°19'E	9-101	3.0	-	38.06	Snark
J7/002/72	10.5.72	1007-1207	41°24'-41°31'S,	174°07'-174°08'E	20-25	4.4	11.7	27.09	James Cook
J7/007/72	19.5.72	1738-1938	41°41'-41°47'S,	174°32'-174°25'E	128	4.1	13.9	10.35	"
J7/008/72	10.5.72	2025-2225	41°50'-41°49'S,	174°23'-174°24'E	75	4.0	-	22.66	"
J7/009/72	11.5.72	1610-0810	42°17'-42°22'S,	173°56'-173°51'E	82	3.4	13.1	16.94	"
J8/001/72	26.5.72	0615-0715	42°22'-42°18'S,	173°51'-173°53'E	62-67	4.8	13.5	21.87	"
J13/005/72	25.9.72	1410-1510	41°55'-41°53'S,	174°19'-174°24'E	128-148	3.8	10.3	9.90	James Cook
J13/017/72	27.9.72	1427-1527	41°17'-41°20'S,	176°05'-176°00'E	57-66	3.3	13.2	2.62	"
J13/026/72	29.9.72	1035-1135	41°44'-41°41'S,	174°59'-174°33'E	113-130	3.6	10.7	3.37	"
J13/028/72	29.9.72	1535-1635	41°28'-41°32'S,	174°12'-174°12'E	27-37	4.1	10.9	21.49	"
	21.9.72	24.50 h	41°23'-41°32'S,	174°03'-174°19'E	9-101	3.0	-	13.84	Snark

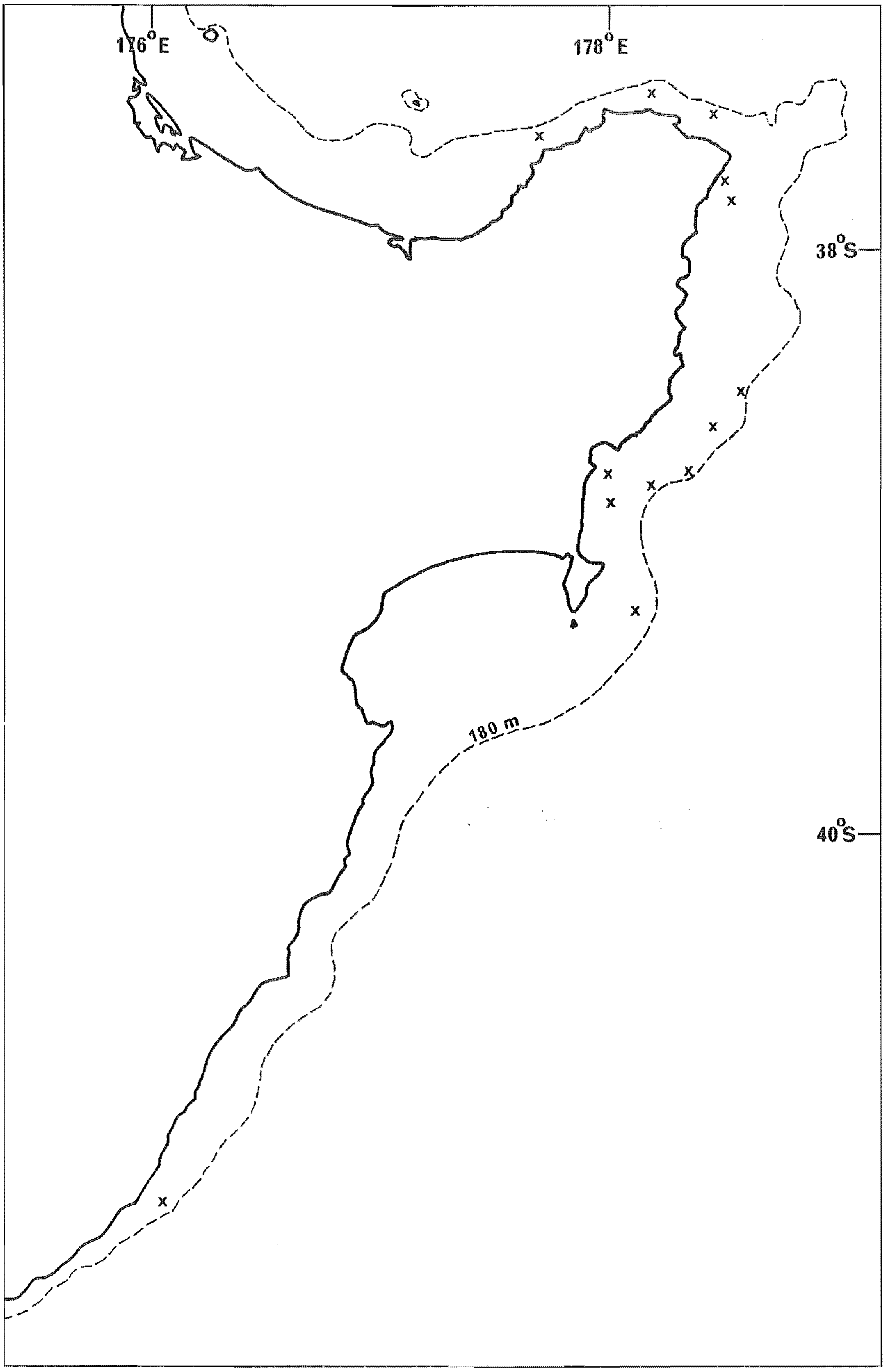


FIGURE 20: East Cape sample stations

Table 11: Catch data for the East Cape area.

Station number	Date	Time trawled	Latitude or Area trawled	Longitude	Depth (m)	Trawl speed (knots)	Water temp. (°C)	Red cod caught (kg)	Vessel
J11/001/73	20.7.73	1322-1422	39°18'-39°15'S,	178°05'-178°06'E	124-135	3.5	14.5	0.14	James Cook
J11/003/73	20.7.73	1634-1734	38°57'-38°54'S,	178°12'-178°13'E	115-117	3.3	14.4	0.78	"
J11/005/73	21.7.73	0652-0752	37°36'-37°34'S,	177°41'-177°44'E	133-155	3.2	16.4	1.39	"
J11/009/73	21.7.73	1100-1200	37°29'-37°29'S,	178°04'-178°09'E	151-173	2.5	16.4	1.11	"
J11/015/73	21.7.73	1705-1805	37°31'-37°32'S,	178°24'-178°27'E	91-132	3.0	15.2	0.51	"
J11/023/73	22.7.73	1255-1355	37°48'-37°51'S,	178°34'-178°31'E	51-64	2.7	14.3	0.38	"
J11/031/73	23.7.73	0835-0935	38°59'-38°55'S,	178°04'-178°03'E	46	3.0	13.9	0.27	"
J11/033/73	23.7.73	1041-1141	38°49'-38°47'S,	177°59'-178°03'E	32-42	3.5	13.2	0.09	"
J11/037/73	24.7.73	1314-1414	38°25'-38°29'S,	178°39'-178°39'E	165-190	3.0	15.8	0.04	"
J11/039/73	24.7.73	1528-1628	38°32'-38°35'S,	178°33'-178°32'E	116-138	3.0	15.3	0.16	"
J11/041/73	24.7.73	1734-1834	38°41'-38°44'S,	178°26'-178°25'E	118-151	2.8	14.5	0.44	"
J11/043/73	25.7.73	0617-0717	37°46'-37°49'S,	178°31'-178°29'E	14-16	3.2	14.0	1.65	"
J11/061/73	26.7.73	1835-1935	41°17 -41°19'S,	176°04'-176°00'E	110-144	3.5	12.0	1.35	"

When the "James Cook" was employed to collect samples, station numbers were recorded in the form of the following example: J14/001/71. J14 was the cruise number, 001 the first station occupied on that cruise, and 71 the year 1971. Full records pertaining to "James Cook" stations are held at the Fisheries Research Division, Ministry of Agriculture and Fisheries, Wellington, New Zealand.

To give a visual impression of the disposition of the successful red cod sampling stations, a figure (Figs 14-20) accompanies each area table.

1.6 Summary

1 A brief synopsis on the codfishes is presented with special mention of New Zealand's best known codfish, the red cod, *Pseudophycis bacchus*.

2 Its distribution is discussed for both New Zealand and Australian waters. The red cod is widely distributed around New Zealand, but its occurrence in Australian waters is doubtful.

3 Reference to previous work is made. These largely insubstantial writings were considered under the headings (1) brief synopses, (2) taxonomy and systematics, (3) anatomy, (4) the red cod fishery, (5) age and growth, (6) food and feeding, (7) reproduction, (8) food value of red cod, (9) parasites, and (10) miscellaneous.

4 The aim of this study is outlined together with its aspects. It was hoped that information could be gained on:
(a) Taxonomy and systematics,
(b) The red cod fishery,
(c) Length frequency, age and growth,
(d) Food and feeding, and
(e) Reproduction.

5 The study areas are defined and their hydrology and oceanic circulation described. My, and other workers', hydrological information was used in the descriptions. The study areas were:
(a) Canterbury,
(b) Otago,

(c) Foveaux Strait,

(d) West Coast South Island (W.C.S.I.),

(e) West Coast North Island (W.C.N.I.),

(f) Cloudy Bay - Cape Campbell (C.B.C.C.), and

(g) East Cape.

6 The sampling programme is discussed as are catch processing and the catching methods. During the period May 1971 - October 1973, 8 131 red cod were taken from the study areas as follows: Canterbury (4 384), Otago (403), Foveaux Strait (142), W.C.S.I. (227), W.C.N.I. (2 019), C.B.C.C. (905), and East Cape (51). The following numbers of fish were fully processed: Canterbury (2 294), Otago (258), Foveaux Strait (122), W.C.S.I. (210), W.C.N.I. (203), C.B.C.C. (219), and East Cape (51). Samples were collected by 16 trawlers.

7 Catch data by area are presented.

8 It is recommended that this work be regarded as preliminary in nature.

SECTION 2

TAXONOMY AND SYSTEMATICS

2.1 Introduction

"The taxonomy of many fish groups is complicated by inadequate original descriptions of closely allied species, the use of characters which vary with age and maturity of the species, and a type concept which limited an adequate statement of the amount of variability present in a species" (Ritchie, 1969). This statement is relevant to the codfishes of the family Moridae in New Zealand waters, and in particular, to the red cod *Pseudophycis bacchus*.

A review of the literature on the red cod has revealed considerable confusion in its classification, and in its systematic position in relation to closely related codfishes of New Zealand and Australia (See Section 1.1 b). Published descriptions for all codfishes are considered to be inadequate.

In this section, the confusion in the red cod classification is resolved and its systematic position clarified. A more adequate description is presented based on results of analyses of samples collected in the Canterbury study area (see Fig. 4).

Descriptive information on closely related species, obtained from analyses of samples from New Zealand waters, is compared with that on the red cod. Although many diagnostic features are similar between species, and some overlap, there are clear differences between the red cod and its close relatives.

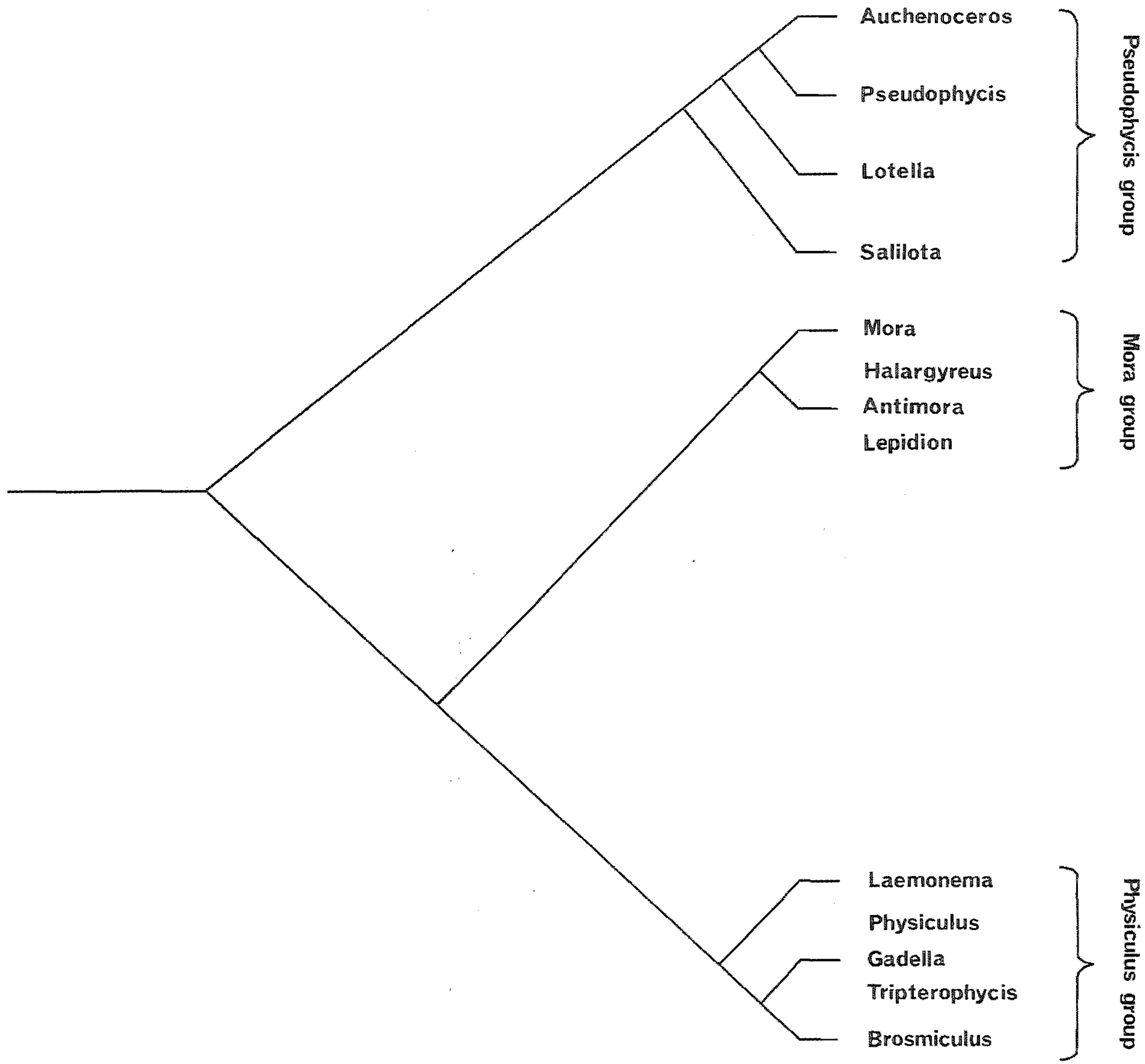
2.2 The codfishes in New Zealand waters

The order Gadiformes (Anacanthini) or cod-like fishes, is represented in New Zealand waters by the suborders Gadoidei, Ophidioidei, Zoarcoidei, and Macrouroidei.

The Gadiformes are rather deep-water fishes of temperate and cold waters. They have moderately elongate bodies covered with small cycloid scales. Dorsal and anal fins are long, the dorsal being divided into two or three parts. The caudal fin is free from dorsal and anal, rounded truncate, or emarginate. The ventral fins are jugular in position and forward of the pectorals. All fins are without true spines. The mouth is large and terminal, and the chin often

FIGURE 21

Systematic relationships of the genera of the Moridae, based in part on Karrer's (1971) interpretation of sagittal otoliths, and in part on a similar study by Fitch and Barker (1972).


Auchenoceros
Pseudophycis
Lotella
Salilota
Pseudophycis group
Mora
Halargyreus
Antimora
Lepidion
Mora group
Laemonema
Physiculus
Gadella
Tripterophycis
Brosmiculus
Physiculus group

has a sensory dermal barbel. The teeth are small and strong, in single rows or villiform bands, sometimes on vomer, palatines and pterygoids. Features of the skull which distinguish the order are parietal bones separated by the supraoccipital; prootic and exoccipital separated by the enlarged opisthotic; the absence of myodome, basi-sphenoid, orbitosphenoid and mesocoracoid; and the first vertebra is attached to the skull. Other characteristic features include all bones without bone cells, no intermuscular bones, and the air bladder is duct-less (Berg, 1940; Svetovidov, 1948).

The more typical codfishes belong to the suborder Gadoidei. These fish characteristically have four or five pectoral radials, small cycloid scales, and normal gills with large openings and with membranes not normally united to the isthmus. Gills extend above the base of the pectoral fins.

This suborder contains the families Moridae, Bregmacerotidae, Gadidae and Merluccidae (see Greenwood, Rosen, Weitzman and Myers, 1966, p. 397). In New Zealand waters, most of the codfishes are in the family Moridae (even *Auchenoceros punctatus*, hitherto considered as belonging to the Bregmacerotidae, is a morid - see Karrer, 1971). The morids are characterized by having vomers without teeth (with one exception - the genus *Mora*), the canal for the olfactory nerves is osseous throughout, on each side of the foramen magnum is a large fontanelle situated in the lateral occipital and covered with a membrane, and a diverticulum of the air bladder adjoins this membrane (Svetovidov, 1937; Berg, 1940). There are also characteristic features of the caudal complex (Rosen and Patterson, 1969), and the sagittal otoliths (Schmidt, 1968; Karrer, 1971; Fitch and Barker, 1972). The last two works have been particularly instrumental in establishing the generic composition and relationships within the Moridae (Fig. 21).

There are 11 genera and 14 species of morids in New Zealand waters (Table 12). Many of the codfishes are little-known deep water species and need only be briefly mentioned. However, two of these little-known species warrant special mention because:

(i) they have not previously been recorded in New Zealand waters, and

(ii) they both resemble the red cod and the distinctions need to be made clear.

These are the codfishes *Pseudophycis marginatus* and *Salilota australis*, previously only reported to occur in the Patagonian-Falklands region, the Straits of Magellan, and off southern Chile (Günther, 1878; Thompson, 1916; Norman, 1937).

Table 12: Codfishes (family Moridae) of the New Zealand region, with one species from Australia.

Genus		species
Pseudophycis	(1)	*bacchus* (Forster in Bloch and Schneider, 1801)
"	(2)	*breviusculus* (Richardson, 1846)
"	(3)	*marginatus* (Günther, 1878)**
Lotella	(4)	*rhacinus* (Forster in Bloch and Schneider, 1801)
Auchenoceros	(1)	*punctatus* (Hutton, 1873)
Mora	(5)	*pacifica* Waite, 1914*
Halargyreus	(6)	*johnsonii* Günther, 1862*
Lepidion	(7)	*microcephalus* Cowper, 1956*
Tripterophycis	(7)	*intermedius* Whitley, 1948*
"	(8)	*gilchristi* Boulenger, 1904*
Melanonus	(8)	*gracilis* Günther, 1878*
Euclichthys	(8)	*polynemus* McCulloch, 1926*
Antimora	(7)	*viola* (Goode and Bean, 1878)*
Salilota	(3)	*australis* (Günther, 1878)**
Pseudophycis	(9)	*barbatus* (Günther, 1863) (Australian)

Key to numbers in parentheses: numbers refer to the following references in which the various species are figured: (1) Waite (1911, pl. 31); (2) Graham (1953, p. 174); (3) Norman (1937, Fig. 24); (4) Doak (1972, pl. 4); (5) Parrott (1948, pl. 30, Fig. 2); (6) Templeman (1968, Fig. 6); (7) Anon (1972b, pp. 278-279); (8) McCann (1972, pp. 626-632); (9) Walker (1972, frontispiece).

* Little-known deep water species

** Also little-known deep water species, but new recordings in New Zealand waters.

The more common codfishes, namely the red cod, *Pseudophycis bacchus*, the bastard red cod, *P. breviusculus*, the rock cod, *Lotella rhacinus*, and ahuru, *Auchenoceros punctatus* also need special mention

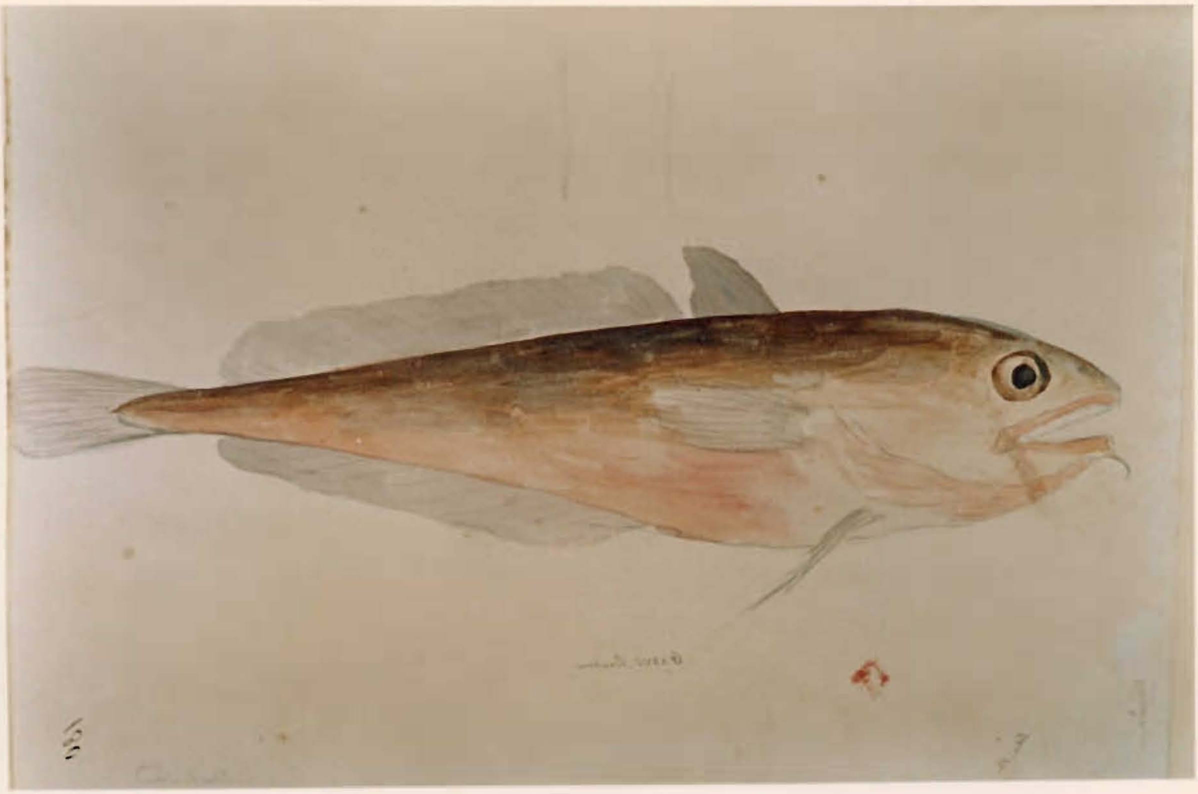
PLATE 1

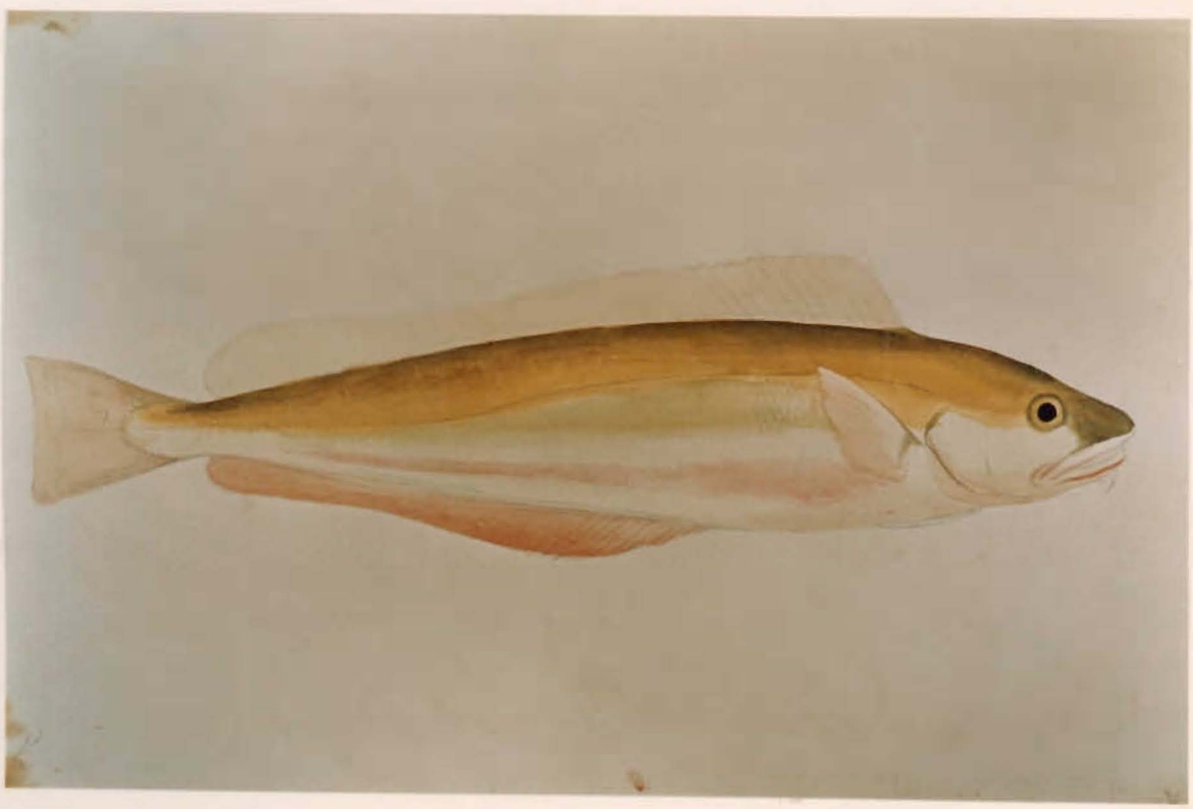
TOP

G. Forster's drawing of the red cod *Pseudophycis bacchus* (*Gadus bacchus*), the specimen on which the original description of this species by J.R. Forster was based (G. Forster's drawing held in the British Museum (Natural History), number 180).

BOTTOM

Sydney Parkinson's drawing of *P. bacchus* (named *Blennius venustus*), the first record of the red cod (Drawing held in the British Museum (Natural History), in volume 2 of Parkinson's drawings, number 5).





because they are often confused, one with another. The first three common species, together with *P. marginatus* and *S. australis*, are discussed in detail later in this section, as is the Australian rock cod *Pseudophycis barbatus*. This species has been confused with the red cod on many occasions (See Section 1.1 b). It has therefore been included in this section to clarify its relationships.

Ahuru may be distinguished from all other morids by its hair-like first dorsal ray, placed over the root of the pectoral fin, and extending backward to beyond the origin of the second dorsal fin.

2.3 The red cod, its classification, synonymy and description

2.3 a Historical review of the nomenclature

The red cod was first seen and drawn by Sydney Parkinson (Plate 1, bottom), artist to Sir Joseph Banks on the first of James Cook's voyages to New Zealand, 1768-1771. The fish was collected from Queen Charlotte Sound (or Totarra'nue), New Zealand (See Fig. 2). This 40.4 cm long fish was named *Blennius venustus* by Parkinson (See Whitehead, 1968).

The first description of this species was made by J.R. Forster, naturalist on Cook's second voyage to New Zealand, 1772-1775. The specimen was collected from Queen Charlotte Sound, and Forster gave it the name *Gadus bacchus*. He presented his description in his manuscript "Descriptiones animalium". The same specimen from which the description was made was drawn by G. Forster (Plate 1, top), artist on the second voyage (For basis of this conclusion see Iredale, 1925).

The first published account of this species was by Bloch and Schneider (1801), and was based on J.R. Forster's manuscript description (Whitehead, 1968). Bloch and Schneider, however, changed the name. Forster's *Gadus* became *Enchelyopus* (which means anguilliform or eel-like) for reasons unknown, and *bacchus* became *bachus*.

I consider Bloch and Schneider's spelling of *bachus* with one "c" to be a *lapsus calami*, either resulting from an inadvertent error, or from a copyists or printer's error (see Article 32(a)(ii) of the International Code of Zoological Nomenclature, 1964). In Forster's manuscript, the specific name *bacchus* was proposed to signify the distinctive red wine colour of this species. *Bacchus*, which refers to the Greek God of wine, or more simply, to wine, is correctly spelt with a double "c". Since Bloch and Schneider were merely reiterating

Forster's description, they should also have followed his spelling of *bacchus*.

Cuvier (1817) followed Forster's lead and used *Gadus bacchus*. In 1829, he again used this name, but on this occasion, he considered *Gadus bacchus* to belong to his genus *Lota*. This effectively changed the name to *Lota baccha*.

Richardson and Gray (1843) and Richardson (1843), confused the issue considerably by referring to red cod under two specific headings. Under *Lota baccha*, they clearly indicated that this referred to Forster's *Gadus bacchus* as presented by Bloch and Schneider (their gadoid species number 69). As species number 71, they listed *Brosmius venustus*, their name for Parkinson's *Blennius venustus*, obviously unaware that Parkinson's and Forster's recordings referred to the same species. They further indicated their lack of awareness by referring Solander's manuscript name *Gadus rubiginosus* ("Pisces Australiae": 49) to Forster's species, and they raised the possibility that Solander's *Blennius rubiginosus* ("Pisces Australiae": 14) ought to have been referred to their species.

In summary, Richardson and Gray erected *Brosmius venustus* as a name for the red cod without being aware of it. Since the red cod at the time was already adequately named, their name has no standing. Nor do Solander's or Parkinson's unpublished names.

In 1844, Forster's manuscript, under the editorship of H. Lichtenstein, was published. Apart from Forster's *Gadus bacchus*, a new synonym arose. In the list of names and synonyms, Lichtenstein pointed out the relationship between *Gadus bacchus* and Bloch and Schneider's *Enchelyopus bacchus*. However, obviously influenced by Forster's lead, he altered Bloch and Schneider's *bachus* to *bacchus*. The new synonym was then *Enchelyopus bacchus*.

The next change in the scientific name of red cod came when Richardson (1846) used *Lota bacchus*.

There was another change in the generic name in 1862. Günther considered that the red cod belonged to the genus *Lotella*, erected by Kaup (1858). This species thus became known as *Lotella bacchus*. Also in 1862, Günther described a new genus *Pseudophycis*, to which he subsequently assigned the red cod, as *Pseudophycis bachus* (Günther, 1880a), and *Pseudophycis bacchus* (Günther, 1880b).

In 1887, Günther, p. 87, combined *Pseudophycis* with *Physiculus* of Kaup (1858), stating that in consequence of the discovery of several intermediate forms, a generic distinction could no longer be maintained between them. He was thus responsible for erecting *Physiculus bacchus*.

Waite (1904) provided the next synonym for the red cod, *Physiculus bachus*. This usage has been by far the most popular ever since.

Other synonyms used have been *Lotella bachus* (Ayson, 1908), *Lota bachus* (Waite, 1921) and *Physiculus* (*Pseudophycis*) *bachus* (Whitley in Graham, 1956).

The most acceptable present day name for the red cod is *Pseudophycis bacchus* (Forster in Bloch and Schneider, 1801). The use of *Pseudophycis* is based on recent taxonomic work on the Moridae, in which sagittal otoliths were used as diagnostic characters (Karrer, 1971; Fitch and Barker, 1972). The use of *bacchus* is based on my earlier argument for a *lapsus calami*. The authorship follows Recommendation 51A(c) of the International Code of Zoological Nomenclature, 1964.

2.3 b Synonymy

Gadus bacchus Forster in Bloch and Schneider, 1801: XXVI, 53 (See Section 2.3 a).

Enchelyopus bachus: Bloch and Schneider, 1801: XXVI, 53 (as far as can be ascertained, no type specimens were deposited. Description from Forster's manuscript description written 1773 in "Descriptiones animalium...").

Gadus bachus of Bloch and Schneider, 1801: XXVI, a mis-spelling of Forster's name *bacchus*.

Gadus bacchus: Cuvier, 1817: 486; Forster in Lichtenstein, 1844: 120, 420.

Lota baccha: Cuvier, 1829: 334; Richardson and Gray, 1843: 221; Richardson, 1843: 26; Gill, 1893: 96, 103.

Brosmius venustus Richardson and Gray, 1843: 222; Richardson, 1843: 27; Taylor, 1855: 413.

Enchelyopus bacchus: Lichtenstein, 1844: 419.

Lota bacchus: Richardson, 1846: 61.

Lotella bacchus: Günther, 1862: 347; Hutton and Hector, 1872: 46, 115; Hector, 1875: 239; 1884: 55; 1886: 28; Hutton, 1875: 134; Thomson, 1877: 485; 1878: 326; 1879: 382; Dambeck, 1879: 536, 547, 555; Parker, 1882: 263; 1883: 234, 235, pl. 33; Sherrin, 1886: 16, 17, 93, 304; Thomson, 1890: 370, pl. 28; 1892: 212; Beattie, 1891: 71, 81, 82, pl. 12, pl. 13, pl. 14, pl. 15; Ayson, 1900: 14; 1907: 22; Mair, 1903: 319; Johnson, 1921: 473; Carter and Malcolm, 1926: 647; Malcolm, 1926: 658; Svetovidov, 1937: 1285; 1948: 17, 60.

Pseudophycis bacchus: Günther, 1880a: 26, 28, 80; Johnston, 1883: 126; Gill, 1893: 94, 95, 100, 120; Murray, 1895: 599; Waite, 1899: 119; Karrer, 1971: 153, 179, 180, 185, 195.

Pseudophycis bachus: Günther, 1880b: 542, 543; Ogilby, 1886: 31; Hutton, 1890: 282; Fitch and Barker, 1972: 572, 573, 574; Marshall and Cohen, 1973: 490.

Physiculus bacchus: Günther, 1887: 87; Goode and Bean, 1895: 365, 549; Hutton, 1896: 316; 1904: 48; Thomson, 1906: 551; Thomson and Anderton, 1921: 74; Thomson and Thomson, 1923: 111; Frost, 1924: 609; 1926: 488, 490; 1933: 140; Young, 1925: 370; Archey in Speight, Wall and Laing, 1927: 203; Anon, 1931: 32; 1971: 17; 1972c: 47; 1973: 3; Benham, 1934: 31; 1935: 22; 1938: 56; Graham, 1938: 405; Doogue and Moreland, 1960: 197, 288; 1961: 208, 316; Moreland, 1963: 20; Webb, 1966: 52, fig. 2.8, 70, 128, table 3.4, 164, 209, 230, 231, 234, 238, 239, 240, 257, 263, 266, 280, 294b, 294c; 1972b: 43; 1973: 307, 308, 309; Heath and Moreland, 1967: 37, 56; Whitehead, 1968: pl. 11; Watkinson and Smith, 1972: 31; Knox and Kilner, 1973: 354; Vooren, 1974: 43, 44.

Physiculus bachus: Waite, 1904: 24; 1907: 18; 1909: 51, 52, 57, 134; 1911: 162, 183, 259, 265, 270, pl. 31; 1921: 67, 78; 1923: 91, 92, 239; 1928: 6; Stead, 1906: 86, 262, 274; 1908: 48, pl. 16; Zietz, 1909: 266; Thomson, 1913: 233; Phillipps, 1918: 271; 1921, 121, 125; 1926: 528; 1927a: 128; 1927b: 23, 60; 1927c: 12; 1947: 42; 1948: 129; 1949: 24, 59; Phillipps and Hodgkinson, 1922: 95; McCulloch, 1921: 42; 1922: XVII, 32; 1929: 129; 1930: 446, 505; Lord and Scott, 1924: 8, 43; Lord, 1927: 13; Young, 1929: 141; Anon., 1930: 28; 1934: 43; 1935: 34; 1957: 69; 1958: 73; 1959: 70; 1960: 70; 1965: 15, 22; 1972a: 229; 1972b: 187, 188, 189, 278; Finlay, 1930: 47; Norman, 1935: 3; 1937: 54, 55; Benham, 1936: 26; 1937: 26, 47; 1940: 35; 1944: 19; Hefford, 1936: 71, 74; Cunningham, 1937: 898; Shorland, 1937: 223; 1948: 109; 1950: 35; Wilson, 1937: 31; Johnston, 1938: 47; Munro, 1938: 62; Graham, 1939b: 364;

1953: 166, 173, 399; Fowler, 1940: 758; Rapson, 1940: 35; Laird, 1949: 14, 19, 36, 37, 39, 53, 56, 60, 61, 137, 145, 146; 1951: 287, 298, 306, 308; 1952: 588, 590, 594, 595, 596, 600; Manter, 1954: 498, 545, 547, 549, 559; Robinson, 1955: 10, 71, 105, pls 9 and 14; 1959: 152; Kaberry, 1957: 90; Moreland in Knox, 1957: 34, 36; Parrott, 1957: 47, 175; 1958: 117; 1960: 67, 164; Meglitsch, 1960: 321, 322, 323; Scott, 1962: 82, 84, 85; Whitley, 1962: 58; 1964: 40; Gorman, 1963: 29; Graham, 1963: 167; Doogue and Moreland, 1964, 1966, 1969: 205, 311; Street, 1964: 18; Churchman, 1965: 56; Elder, 1966: 96, 97; Howell, 1966: 33; McLintock, 1966: 708; Paul, 1966: 372, 373; Svetovidov, 1967: 1685, 1686, 1689, 1690; Sorensen, 1968: 148; 1970: 4, 17; Tong and Elder, 1968: 64; Russell, 1969: 108; 1971a: 9, 19, 21, fig. 3, 38, 41, 94, 173, table 10, fig. 13, 191, 197; 1971b: 83; Cowper, 1970: 45; Godfriaux, 1970: 257; 1974: 502; Iwai, Nakamura, Inada, Ikeda, Sato and Hatanaka, 1970: 21; 1972: 29, 36; Shuntov, 1970: 373, 374, 376; 1972: 339; Coakley, 1971: 24; Doak, 1972: 19, 101, 131; Hewitt and Hine, 1972: 92; Walker, 1972: 2; Webb, 1972a: 16; Suda, 1973: 2150, 2151, 2152; Waugh in Williams, 1973: 257, 274; Williams, 1973b: 427; Ryan, 1974: 133, 135; Scott, Glover and Southcott, 1974: 93, 95, 96, 378, 385.

Lotella bachus: Ayson, 1908: 28; Rendahl, 1926: 2.

Lota bachus: Waite, 1921: 67.

Physiculus (Pseudophycis) bachus: Whitley in Graham, 1956: 403; Graham, 1956: 166, 173, 403; Whitley, 1968: 40.

2.3 c Description - general

2.3 c i Material examined

This is listed in Table 13.

2.3 c ii Morphometric measurements

The following body dimensions were measured to the nearest o.5 mm, point to point, with dividers, using the methods outlined by Hubbs and Lagler (1947) and Svetovidov (1948): total length (TL), tip of snout to tip of caudal fin; standard length (SL), tip of snout to hypural crease; head length (HL), tip of snout to furthest posterior point of opercular membrane; snout length (SnL), tip of snout to anterior margin of orbit; orbit diameter (OD), longitudinal diameter of orbit; post-orbital head length (POHL), posterior border of orbit to furthest posterior point of opercular membrane; upper jaw length (UJL), total length of upper jaw; inter-orbital width (IOW), width between the inside edges of the orbits; caudal length (CL), hypural crease to end of caudal fin.

Table 13: Length and sex composition of red cod samples from the Canterbury area examined for morphometric and meristic variation.

Length class (cm)	Females	Males
0 - 5	1	0
6 - 10	2	3
11 - 15	3	1
16 - 20	6	5
21 - 25	7	6
26 - 30	7	6
31 - 35	4	8
36 - 40	6	8
41 - 45	11	11
46 - 50	7	6
51 - 55	6	7
56 - 60	3	10
61 - 65	6	7
66 - 70	5	5
71 - 75	1	2
Totals	75	85

Head length, post-orbital head length, orbit diameter, upper jaw length and caudal length are expressed as percentages of standard length to standardize these measurements between fish of different lengths. Likewise, orbit diameter, upper jaw length, snout length, and inter-orbital width are expressed as percentages, this time of head length.

Measurements were made on both fresh and preserved material, and the differences due to the effects of preservative were taken into account (See Section 1.5 b). No sexual differences were detected. Therefore, all fish listed in Table 13 were processed together.

2.3 c iii Meristic counts

Counts were made on fin rays in the first and second dorsal, anal, caudal, pectoral, and pelvic fins, of gill rakers on the upper and lower arms of the first gill arch, and of pyloric caeca. As with the morphometric analyses, no sexual differences were found and therefore all fish were processed together.

Results of both morphometric and meristic analyses are presented in Tables 14-15 where they are located to facilitate comparisons with closely related codfishes.

The morphometric percentages in the description are mean values calculated from the Canterbury samples. I found that the morphometrics of red cod from other parts of New Zealand are very similar to those of Canterbury area red cod (Observations on 50 red cod from each of the other areas).

The meristic ranges in the description were based partly on the Canterbury samples, and partly on those reported in the literature. As such, these results are representative of red cod from throughout the New Zealand region.

2.3 c iv Description

Body elongate, compressed, trunk almost round, tapering posteriorly, greatest depth at about mid-abdomen; caudal peduncle moderately long and slender. Head moderate, rather broad, depressed above eye, 24.44% of standard length; snout depressed, pointed in juveniles, bluntly pointed in adult fish, 26.38% of head length; orbit large, near to upper profile of head, 20.6% of head length, 5.10% of standard length; post-orbital head length 12.60% of standard length; interorbital space broad and flat, 33.77% of head length. Mouth moderate in size, sub-horizontal, maxilla extending to underlie hinder margin of orbit, upper jaw slightly longer, 51.56% of head length, 12.51% of standard length; villiform teeth in bands in both jaws, none on tongue, vomer, or palatines; lips thin; small barbel near tip of lower jaw. Gill rakers moderate in length, 3-6 on upper arm of first gill arch, 9-13 on lower; 6-7 pyloric caeca. Head and body entirely covered with small scales, those of lateral line differing in being generally

Table 14: Variations in head length (HL), orbit diameter (OD), post-orbital head length (POHL), upper jaw length (UJL) and caudal length (CL) expressed as percentages of standard length (SL), and variations in UJL, snout length (SnL), and inter-orbital width (IOW) expressed as percentages of head length, in various codfishes from New Zealand and Australia. Also presented are length range of the samples (cm), and the sample size (n).

		Pseudophycis bacchus (5.0-75.0 cm) n = 160	*P. breviusculus* (11.1-42.4 cm) n = 12	*P. marginatus* (12.8-16.0 cm) n = 5	*P. barbatus* (19.7-31.5 cm) n = 5	*Lotella rhacinus* (18.3-33.1 cm) n = 5	*Salilota australis* (6.4-7.5 cm) n = 5
HL/SL	Min.	22.25	21.46	21.21	26.29	24.44	23.13
	Mean	24.44	24.25	21.68	26.46	25.65	23.83
	Max.	26.57	28.07	22.58	28.24	26.81	24.15
	s^2	0.84	3.98	0.32	1.17	0.88	0.18
	s	0.92	1.99	0.57	1.08	0.94	0.42
	$s\bar{y}$	0.72	0.58	0.25	0.48	0.42	0.19
	cv	3.75	8.20	2.63	4.08	3.66	1.76
OD/SL	Min.	3.95	5.22	8.54	5.15	4.90	7.44
	Mean	5.10	6.53	8.90	5.53	5.48	7.96
	Max.	5.95	8.29	9.27	7.06	6.44	8.62
	s^2	0.23	0.98	0.08	0.79	0.53	0.27
	s	0.48	0.99	0.29	0.89	0.73	0.52
	$s\bar{y}$	0.07	0.31	0.13	0.35	0.33	0.23
	cv	9.41	15.16	0.90	16.09	13.32	6.53

Table 14: Continued

		Pseudophycis bacchus (5.0-75.0 cm) n = 160	*P. breviusculus* (11.1-42.4 cm) n = 12	*P. marginatus* (12.8-16.0 cm) n = 5	*P. barbatus* (19.7-31.5 cm) n = 5	*Lotella rhacinus* (18.3-33.1 cm) n = 5	*Salilota australis* (6.4-7.5 cm) n = 5
POHL/SL	Min.	10.74	11.65	8.18	13.98	13.89	10.11
	Mean	12.60	13.44	8.65	14.45	14.36	10.22
	Max.	13.29	16.58	9.27	14.81	15.03	10.34
	s^2	0.29	2.68	0.19	0.48	0.22	0.06
	s	0.54	1.63	0.44	0.69	0.47	0.08
	$s\bar{y}$	0.09	0.52	0.20	0.31	0.21	0.04
	cv	4.26	12.12	5.09	4.77	3.27	0.78
UJL/SL	Min.	11.40	11.22	10.34	13.86	12.09	10.69
	Mean	12.51	12.61	10.54	14.09	13.43	11.25
	Max.	13.61	14.88	10.68	14.97	14.94	11.57
	s^2	0.29	1.90	0.02	0.52	1.77	0.12
	s	0.54	1.38	0.14	0.72	1.33	0.35
	$s\bar{y}$	0.08	0.46	0.06	0.32	0.59	0.16
	cv	4.32	10.94	1.33	5.11	9.90	3.11

Table 14: Continued

		Pseudophycis bacchus (5.0-75.0 cm) n = 160	*P. breviusculus* (11.1-42.4 cm) n = 12	*P. marginatus* (12.8-16.0 cm) n = 5	*P. barbatus* (19.7-31.5 cm) n = 5	*Lotella rhacinus* (18.3-33.1 cm) n = 5	*Salilota australis* (6.4-7.5 cm) n = 5
	Min.	9.76	10.27	8.33	8.63	9.17	9.09
	Mean	10.60	11.07	9.14	9.49	10.64	10.74
	Max.	12.16	11.97	9.68	11.30	11.59	11.94
CL/SL	s^2	1.04	0.19	0.30	1.46	1.05	1.12
	s	1.02	0.44	0.55	1.21	1.02	1.05
	$s\bar{y}$	0.17	0.13	0.13	0.54	0.46	0.47
	cv	9.62	3.97	6.02	12.75	9.59	9.78
	Min.	16.48	25.00	40.00	19.58	18.75	31.03
	Mean	20.69	29.04	41.00	20.26	20.76	33.57
	Max.	24.67	33.33	41.94	25.00	22.22	35.71
OD/HL	s^2	3.67	10.38	0.47	9.18	1.65	3.55
	s	1.92	3.22	0.69	3.03	1.28	1.88
	$s\bar{y}$	0.17	1.21	0.31	1.36	0.57	0.84
	cv	9.26	11.09	1.69	14.96	6.17	5.60

Table 14: Continued

		Pseudophycis bacchus (5.0-75.0 cm) n = 160	*P. breviusculus* (11.1-42.4 cm) n = 12	*P. marginatus* (12.8-16.0 cm) n = 5	*P. barbatus* (19.7-31.5 cm) n = 5	*Lotella rhacinus* (18.3-33.1 cm) n = 5	*Salilota australis* (6.4-7.5 cm) n = 5
	Min.	48.34	47.91	46.43	52.74	48.75	46.87
	Mean	51.56	51.39	48.75	53.49	52.02	48.02
	Max.	54.71	53.78	50.00	53.52	54.74	48.39
UJL/HL	s^2	1.99	3.26	2.17	1.21	6.65	0.41
	s	1.41	1.81	1.47	1.10	2.58	0.64
	$s_{\bar{y}}$	0.12	0.60	0.66	0.49	1.15	0.18
	cv	2.74	3.52	3.02	2.06	4.96	0.85
	Min.	22.06	15.21	17.74	22.54	21.12	27.58
	Mean	26.38	17.34	19.48	25.56	22.48	30.83
	Max.	29.45	21.82	21.67	25.87	24.20	34.37
SnL/HL	s^2	3.34	12.91	2.87	3.73	1.84	7.00
	s	1.83	3.59	1.69	1.93	1.36	2.64
	$s_{\bar{y}}$	0.16	1.60	0.75	0.86	0.61	1.18
	cv	6.93	20.70	8.68	7.55	6.06	8.56

Table 14: Continued

		Pseudophycis bacchus (5.0-75.0 cm) n = 160	*P. breviusculus* (11.1-42.4 cm) n = 12	*P. marginatus* (12.8-16.0 cm) n = 5	*P. barbatus* (19.7-31.5 cm) n = 5	*Lotella rhacinus* (18.3-33.1 cm) n = 5	*Salilota australis* (6.4-7.5 cm) n = 5
	Min.	30.62	22.73	17.74	33.56	27.78	22.86
	Mean	33.77	27.63	17.97	35.51	29.61	23.36
	Max.	37.79	31.20	18.33	35.66	31.42	24.13
IOW/HL	s^2	42.44	8.29	0.05	17.04	1.86	0.28
	s	6.51	2.88	0.22	4.13	1.36	0.53
	$s\bar{y}$	0.87	0.91	0.10	1.85	0.61	0.24
	cv	19.21	10.42	1.22	11.63	4.59	2.27

Table 15: Numbers of fin rays, gill rakers, and pyloric caeca in various codfishes from New Zealand and Australia (details of species length ranges and sample size presented in Table 14).

		P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
First dorsal fin rays	Min.	9.00	7.00	7.00	9.00	5.00	9.00
	Mean	10.34	8.08	7.77	9.80	6.00	10.00
	Max.	12.00	9.00	8.00	11.00	9.00	11.00
	s^2	1.75	0.45	12.06	0.70	4.00	0.50
	s	1.32	0.67	3.47	0.84	2.00	0.71
	$s\bar{y}$	0.80	0.19	1.15	0.37	0.89	0.32
	cv	12.81	8.29	44.65	8.57	33.33	7.10
Second dorsal fin rays	Min.	40.00	46.00	58.00	48.00	54.00	54.00
	Mean	42.77	49.42	58.56	53.00	57.60	58.00
	Max.	46.00	54.00	60.00	57.00	64.00	61.00
	s^2	2.15	9.54	0.53	11.00	14.80	8.50
	s	1.47	3.09	0.72	3.32	3.85	2.92
	$s\bar{y}$	0.13	0.89	0.24	1.49	1.72	1.30
	cv	3.43	6.25	1.23	6.26	6.68	5.03

Table 15: Continued

		P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
Anal fin rays	Min.	40.00	48.00	57.00	48.00	50.00	55.00
	Mean	44.95	51.08	57.78	52.40	54.00	56.00
	Max.	50.00	54.00	58.00	56.00	58.00	57.00
	s^2	4.83	3.36	0.25	8.80	10.00	0.50
	s	2.20	1.83	0.50	2.97	3.16	0.71
	$s_{\bar{y}}$	0.24	0.53	0.17	1.31	1.41	0.32
	cv	4.89	3.58	0.87	5.67	5.85	1.27
Caudal fin rays	Min.	31.00		33.00	28.00	26.00	
	Mean	34.00	26.00	33.78	30.00	28.00	33.00
	Max.	37.00		34.00	32.00	31.00	
	s^2	1.90		0.19	2.00	7.50	
	s	1.38		0.44	1.41	2.74	
	$s_{\bar{y}}$	0.15		0.15	0.63	1.22	
	cv	4.06		1.30	4.70	9.79	

Table 15: Continued

		P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
	Min.	22.00	19.00	23.00	22.00	23.00	23.00
	Mean	24.03	23.33	23.78	23.80	24.00	24.40
	Max.	26.00	26.00	24.00	26.00	26.00	25.00
Pectoral fin rays	s^2	0.95	4.24	0.19	2.20	1.50	0.80
	s	0.98	2.06	0.44	1.48	1.22	0.89
	$s\bar{y}$	0.09	0.59	0.15	0.66	0.54	0.39
	cv	4.06	8.83	1.30	6.22	5.08	3.64
	Min.	5.00					7.00
	Mean	5.06	5.00	7.00	5.00	7.00	7.20
	Max.	6.00					8.00
Pelvic fin rays	s^2	0.06					0.20
	s	0.24					0.45
	$s\bar{y}$	0.03					0.20
	cv	4.70					6.25

Table 15: Continued

		P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
Gill rakers upper arm first arch	Min.	3.00		4.00	2.00		
	Mean	4.58	3.00	5.52	3.20	4.00	6.00
	Max.	6.00		6.00	4.00		
	s^2	0.29		0.44	0.70		
	s	0.54		0.67	0.84		
	$s\bar{y}$	0.04		0.22	0.38		
	cv	11.74		12.83	26.25		
Gill rakers lower arm first arch	Min.	8.00	6.00	14.00	9.00		
	Mean	10.40	8.25	14.33	10.20	9.00	15.00
	Max.	13.00	10.00	15.00	11.00		
	s^2	0.48	1.11	0.22	0.70		
	s	0.69	1.05	0.47	0.84		
	$s\bar{y}$	0.05	0.30	0.16	0.38		
	cv	6.63	12.73	3.28	8.34		

Table 15: Continued

		P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
	Min.	6.00	16.00	8.00			8.00
	Mean	6.05	17.42	8.89	10.00	16.00	8.40
	Max.	8.00	20.00	9.00			9.00
Pyloric caeca	s^2	0.08	2.63	0.11			0.30
	s	0.29	1.62	0.33			0.55
	$s\bar{y}$	0.03	0.47	0.11			0.25
	cv	4.79	9.30	3.71			6.55

oval in shape; lateral line well marked, forming a long arch to below middle of second dorsal fin, straightening to caudal.

All fins with rays; dorsal fin divided into two parts, dorsal 1 (D1) separated from D2 by a short space; D1 commences at a vertical drawn from origin of pectoral fin, rays few (9-12), fin short and semi-triangular; D2 long (39-48 rays), extending to caudal peduncle, front and rear rays higher than central rays; anal fin similar to D2, 40-50 rays; pectoral fins pointed, 22-26 rays; pelvic fins set forward of pectorals, emerging ventrally below middle of post-orbital; small, pointed, 5-6 rays; caudal fin moderate, 10.60% of standard length, nearly square across end, 32-36 rays.

In life, colour predominantly reddish-grey above, pink-grey laterally, and pink-white below; a black blotch behind operculum at upper base of pectoral; all fins grade from red to pink to grey-white; caudal sometimes edged with black; on removal from water, red and pink colours intensify, hence the common name.

Size

P. bacchus has been reported to grow to 122 cm TL and attain a weight of more than 6 kg. These records are doubtful: maximum values obtained in the present study were 78.3 cm and 4.92 kg respectively. Average values for mature adult fish were 55 cm and 2 kg.

2.3 d Red cod compared with some other New Zealand codfishes

2.3 d i Statistics

Morphometric and meristic variations in *P. bacchus*, *P. breviusculus*, *P. marginatus*, *P. barbatus*, *L. rhacinus* and *S. australis* are presented in Tables 14 and 15. Morphometric measurements and counts were carried out as indicated in 2.3 c ii and 2.3 c iii. The results of other observations are found in Table 16.

In all but Table 16, various statistics are presented. Min. (for minimum), mean, and Max (maximum) are self-explanatory. The symbol s^2 stands for variance, s for standard deviation, $s\bar{y}$ for standard error of the mean, and cv for the coefficient of variation (for explanation of these statistics, see Sokal and Rohlf, 1969).

Table 16: Other observations on various codfishes from New Zealand and Australia (details of species length ranges and sample size presented in Table 14).

	P. bacchus	*P. breviusculus*	*P. marginatus*	*P. barbatus*	*L. rhacinus*	*S. australis*
Shape of caudal	square	rounded	square	rounded	rounded	rounded
Relative size caudal	large	small	small	large	small	small
Pectoral blotch	present	absent	absent	present	absent	absent
Black fin margins	sometimes	present	absent	present	present	absent
Colour	see above	similar to *p. bacchus* but more pink	pink-red	red-brown to dark brown	uniformly dark red	pink-red
Lips	thin	thin	thin	thin	thick	thin
Gape - eye relationship	see above	maxillary not reaching hinder border of eye	to vertical under pupil of eye	to beyond hinder border of eye	to vertical under pupil of eye	maxillary almost to hinder border of orbit
Spawning season	Sep-Nov	Jan-Feb	unknown	unknown	unknown	unknown
Maximum recorded size (cm)	see above	unknown	22.5	62.5	42.0	47.0

2.3 d ii Sources of samples

The source of the red cod samples is indicated in Section 2.3 c i. For other species, locality, date, number of fish and collector are listed in Table 17a.

Table 17a: Sources of other codfishes

Species	Position	Date of collection	Number of fish	Collector
P. breviusculus	40°51'S, 173°08'E	13.9.71	2	James
	40°41'S, 172°46'E	13.9.71	2	James
	40°31'S, 175°06'E	10.11.71	1	James
	42°59'S, 173°51'E	14.6.72	2	Chant
	37°49.2'S, 178°39'E	25.7.73	2	Habib
	40°34.4'S, 176°33.3'E	26.7.73	3	Habib
P. marginatus	47°09.8'S, 169°28.4'E	14.8.71	5	Habib
P. barbatus	Derwent Estuary, Tasmania	Aug. 1973	5	Dix
L. rhacinus	42°24'S, 173°42'E	June 1972	1	Bowring
	41°7.6'S, 173°59.2'E	Feb 1973	1	Tortell
	38°47.2'S, 178°03.5'E	23.7.73	3	Habib
S. australis	42°59.4'S, 175°26.5'E	23.1.54	2	Moreland
	43°40'S, 179°28'E	24.1.54	3	Moreland

2.3 d iii Discussion

There are similarities and differences between all species throughout the range of the parameters measured. For example, the percentages of head length in standard length (HL/SL) for *P. bacchus*, *P. breviusculus*, and *S. australis* were quite similar; but all three species differed considerably for OD/SL (Table 14). Many other such comparisons are possible. However, for the purposes of the present study, it is sufficient to note how *P. bacchus* differs from its close relatives. The rest of the information is available for future work on these New Zealand codfishes.

2.3 d iii (1) Comparisons

In the following comparisons, differences are emphasized. All differences were significant in that the ranges around the mean values for the parameters overlapped only a little, if at all (For details, see Tables 14-16).

P. bacchus - P. breviusculus: Differences occurred in OD/HL, Sn/HL, and IOW/HL; in the number of rays in the first and second dorsal, and caudal fins; in the shape of the tail and its relative size; in the number of pyloric caeca; in the presence/absence of a pectoral blotch; in the gape-eye relationship; and in the spawning season.

P. bacchus - P. marginatus: Differences occurred in HL/SL, OD/SL, POHL/SL, UJL/SL, CL/SL, SnL/HL, and IOW/HL; in the number of rays in the first and second dorsal, anal and pelvic fins; in the number of gill rakers on the lower arm of the first gill arch; in the relative size of the tail; in the number of pyloric caeca; in the presence/absence of a pectoral blotch; and in the gape-eye relationship.

P. bacchus - P. barbatus: There were differences in POHL/SL and UJL/SL; in the number of second dorsal fin rays; in the shape of the tail; in the number of pyloric caeca; and in colour.

P. bacchus - L. rhacinus: The POHL/SL differed, as did the number of rays in the first and second dorsal, anal, caudal and pelvic fins; and the number of pyloric caeca; the tail shape and relative size; the presence/absence of a pectoral blotch; the relative size of the lips; and the gape-eye relationship.

P. bacchus - S. australis: Differences occurred in OD/SL, OD/HL and IOW/HL; in the number of rays in the second dorsal fin and in anal and pelvics; in the number of gill rakers on the lower arm of the first gill arch; in the shape and relative size of the tail; in the number of pyloric caeca; and in the presence/absence of a pectoral blotch.

It must be emphasized that the above differences are based on measurements and counts on my own samples. However, findings generally were in agreement with those of other workers as reported in the literature.

Using information presented in Tables 14-16, a simple key was constructed to enable the species listed in these tables to be rapidly distinguished (Table 17b). Also included in the key is *Auchenoceros punctatus*.

Table 17b: Key to the codfishes listed in Tables 14-16, as well as to *Auchenoceros punctatus*.

All with 2 dorsal fins, 1 anal fin, barbel under chin.

1.	Caudal margin square	2
	Caudal margin rounded	4
2.	Pectoral blotch present	*Pseudophycis bacchus*
	Pectoral blotch absent	3
3.	First dorsal ray hairlike, extending backward beyond origin of second dorsal	*Auchenoceros punctatus*
	First dorsal ray not hairlike, first dorsal fin semi-triangular	*Pseudophycis marginatus*
4.	Pectoral blotch present	*Pseudophycis barbatus*
	Pectoral blotch absent	5
5.	Pyloric caeca 8-9	*Salilota australis*
	Pyloric caeca more than 9	6
6.	Pyloric caeca 16; gape to vertical under eye, second dorsal 54-64 rays	*Lotella rhacinus*
	Pyloric caeca 16-20; gape not extending to hinder border of eye; second dorsal 46-54 rays	*Pseudophycis breviusculus*

The above species may be distinguished from the rest of the New Zealand morids (see Table 12) as follows:

(i) The following species have 2 anal fins - *Mora pacifica, Halargyreus johnsonii, Euclichthys polynemus, Lepidion microcephalus,* and *Antimora viola;*

(ii) these species have 3 dorsal fins - *Tripterophycis intermedius* and *T. gilchristi;*

(iii) *Melanonus gracilis* is similar to the more common morids in having 2 dorsals and 1 anal. But it is distinguishable in that it has no barbel.

2.4 Summary

1 Confusion in the taxonomy and systematics of the New Zealand codfishes of the family Moridae is indicated.

2 The members of this family present in New Zealand waters (and one Australian species) are listed, together with distinguishing features of their higher classification.

3 Generic relationships of the Moridae are indicated based on studies of structure of otoliths.

4 The history of the naming of the red cod is presented, and it is shown that the most acceptable present day name is:

Pseudophycis bacchus (Forster in Bloch and Schneider, 1801).

5 The synonymy of the red cod is presented. Fifteen synonyms have been used in 193 references. The synonyms in order of usage are *Enchelyopus bachus, Gadus bachus, Gadus bacchus, Lota baccha, Brosmius venustus, Enchelyopus bacchus, Lota bacchus, Lotella bacchus, Pseudophycis bacchus, Pseudophycis bachus, Physiculus bacchus, Physiculus bachus, Lotella bachus, Lota bachus*, and *Physiculus (Pseudophycis) bachus*.

6 The red cod is described from morphometric and meristic analyses of 160 fish from the Canterbury study area.

7 Similar analyses were carried out on the codfishes *Pseudophycis breviusculus, P. marginatus, P. barbatus, Lotella rhacinus*, and *Salilota australis*. The differences between these species and the red cod are highlighted.

8 A simple key for the above species is presented. The key also includes *Auchenoceros punctatus*.

9 Features of the less common codfishes are listed so that they can be rapidly distinguished from the more common species.

SECTION 3

THE RED COD FISHERY

3.1 Introduction

The red cod *Pseudophycis bacchus* is a marine fish of some commercial importance in the New Zealand fishery. With a range which encompasses most of the coastal waters of New Zealand and its offshore islands, this species may be found from the shore into depths of over 750 metres. Primarily a bottom dwelling or ground fish, it may be found throughout the levels of the sea at times, these movements being in response to movements of prey species such as the galatheid *Munida gregaria* (Fabricius).

Red cod occur in abundance in New Zealand waters (Shuntov, 1970, 1972), at times in great abundance (Sherrin, 1886; Ayson, 1900; Thomson, 1913; Graham, 1938, 1953; Moreland in Knox, 1957; Shuntov, pers. comm.). They are most abundant in the southern parts of their range, especially off the east coast of the South Island between latitude 42° and 46° South. Occasional abundances do however occur outside this prescribed area, especially north of latitude 42° South, off the west coast of the South Island and in Tasman and Golden Bays.

However, this abundance has until recently meant little in terms of marketability. Over the years, demand has been low owing to the softness of its flesh (Thomson and Anderton, 1921; Phillipps, 1949; Graham, 1953; Parrott, 1957; Waugh in Williams, 1973), to the food red cod eat (Graham, 1953; Parrott, 1957), and to the parasites this species carries (Graham, 1953). Large quantities have been returned to the sea (Waite, 1911; Graham, 1953; Watkinson and Smith, 1972; Vooren, 1974). Such bias against red cod was unwarranted for the reasons given by Graham.

Since 1966-1967, market outlets have been developed (Coakley, 1971, Watkinson and Smith, 1972). This, combined with modern marketing techniques, has led to red cod now being a common species in fish markets.

3.2 The red cod fishery in New Zealand

3.2. a Introduction

Considerable information on the red cod fishery in New Zealand is obtainable from fish landing statistics released by the Ministry of Agriculture and Fisheries (MAF), until 1972 known as the Marine Department. Annual reports in comparable form have been compiled since 1936 (See Vooren, 1974, p. 11 for explanation). Results of analysing the statistics presented in these reports can be found in the following subsections. Results for the New Zealand total wetfish catch are presented for comparison.

3.2 b Fish landing statistics 1936-1973

3.2 b i General

Results of analysing these MAF statistics are presented in Figures 22a and b. Figure 22a shows the manner in which the red cod landings in New Zealand have fluctuated during the last 38 years, and it also shows that the percentage worth of red cod in the total New Zealand wetfish landings has had similar fluctuations.

Figure 22b shows on the one hand a more or less steady rate of increase in the New Zealand total wetfish landings from the low point to which these declined in 1943 to the high point in 1973. On the other hand, the percentage red cod content in these New Zealand totals fluctuated considerably in a manner similar to the lines in Figure 22a, as would be expected.

3.2 b ii The New Zealand total wetfish landings (Fig. 22b)

There was a direct relationship between the fluctuations in wetfish landings and the number of wetfish fishing vessels working in New Zealand waters during the period 1936-1972. This can be seen by relating data in Table 18 to Figure 22b landings.

The decline in landings from 1936-1943 was almost certainly related to the drop in number of wetfish vessels fishing. From 1939 to 1943, this drop can be attributed to a shortage of manpower and equipment resulting from the war (Vooren, 1974, p. 26). Subsequently, the number of vessels rose as did the landings.

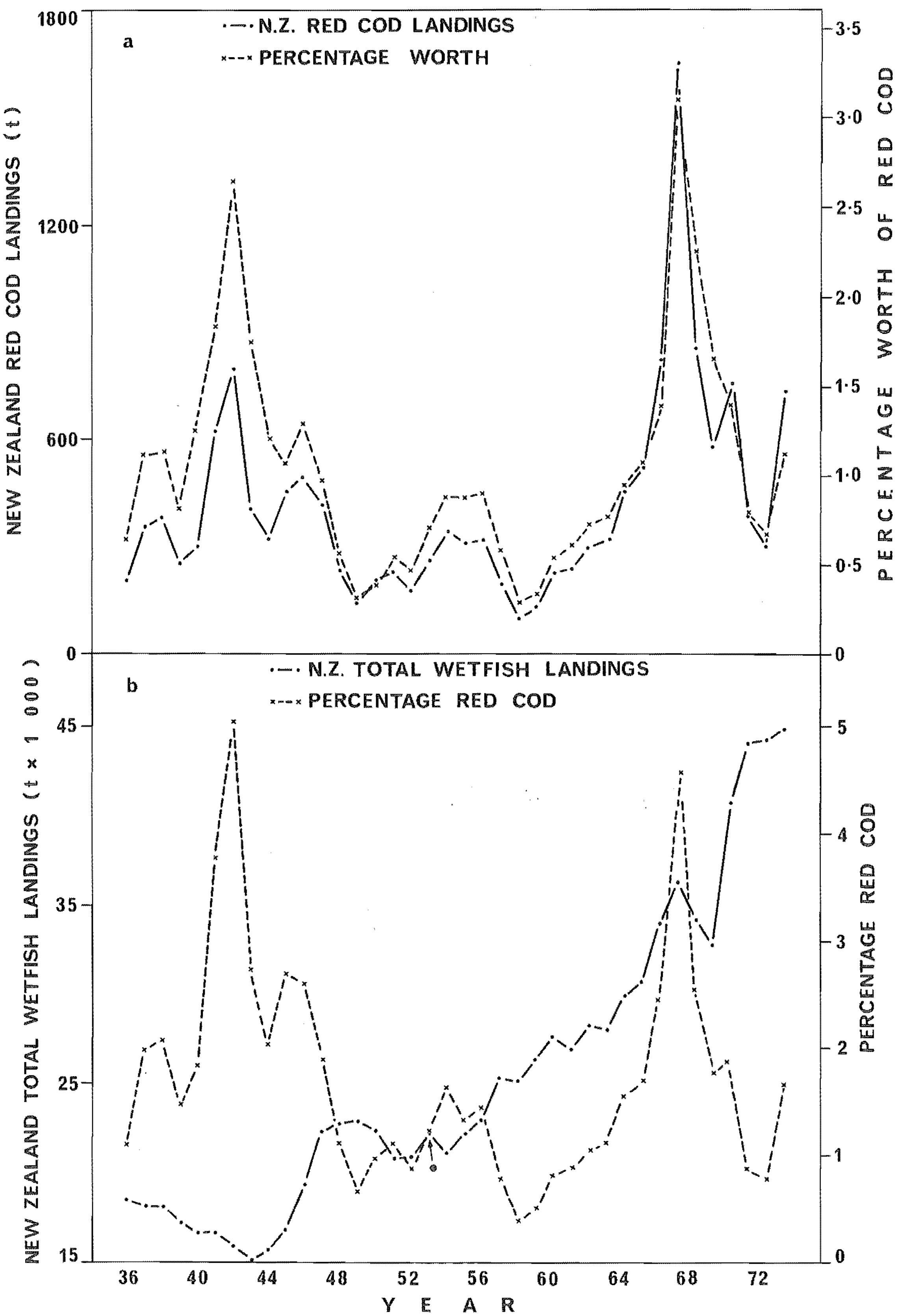
If the number of vessels fishing in any one year is considered as the total fishing effort for that year, a measure of catch/effort can be gained by dividing the number of vessels into the total wetfish catch,

FIGURE 22a

New Zealand red cod landings and the percentage worth of these landings in the New Zealand total wetfish landings.

FIGURE 22b

New Zealand total wetfish landings and the percentage of red cod in these landings.



N.Z. RED COD LANDINGS
PERCENTAGE WORTH
a
1800
1200
600
0
NEW ZEALAND RED COD LANDINGS (t)
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
PERCENTAGE WORTH OF RED COD
N.Z. TOTAL WETFISH LANDINGS
PERCENTAGE RED COD
b
45
35
25
15
NEW ZEALAND TOTAL WETFISH LANDINGS (t × 1 000)
5
4
3
2
1
0
PERCENTAGE RED COD
36
40
44
48
52
56
60
64
68
72
YEAR

Table 18: The number of vessels fishing for wetfish in New Zealand waters, 1936-1973.

Year	Number of Vessels	Year	Number of Vessels
1936	1 109	1955	1 282
1937	1 061	1956	1 317
1938	1 145	1957	1 372
1939	1 118	1958	1 619
1940	834	1959	1 540
1941	813	1960	1 511
1942	734	1961	1 587
1943	662	1962	1 757
1944	731	1963	1 918
1945	709	1964	1 525
1946	781	1965	1 599
1947	707	1966	1 764
1948	753	1967	1 938
1949	1 110	1968	2 099
1950	1 123	1969	2 250
1951	1 129	1970	2 422
1952	1 161	1971	2 542
1953	1 251	1972	2 648
1954	1 384	1973	2 852

thus obtaining the average landing per vessel per year. This, Vooren (1974) called the catch/trawler-year, where his vessels were trawlers. In the present study, this statistic will be referred to as the landing/vessel-year because, for red cod, landings were probably not always synonymous with catches (See Vooren, 1974, p. 11).

For the New Zealand total wetfish landings for 1936-1973, landings/vessel-year are presented in Table 19.

It should be pointed out that the number of vessels in Table 18 includes for any one year, a large number of small line and net-setting vessels, many of which were mere rowing boats. However the majority of wetfish is landed by the much larger trawlers. The values for landings/vessel-year in Table 19 therefore are underestimates in relation to the main landing method. Nevertheless, the trends would be the same.

Table 19: Landings/vessel-year of the New Zealand total wetfish landings, 1936-1973.

Year	Landings/vessel-year (t)	Year	Landings/vessel-year (t)
1936	16.65	1955	17.27
1937	17.05	1956	17.41
1938	15.81	1957	18.47
1939	15.43	1958	15.52
1940	20.03	1959	17.10
1941	20.44	1960	18.26
1942	21.61	1961	16.94
1943	22.62	1962	16.05
1944	21.44	1963	14.61
1945	23.80	1964	19.65
1946	24.76	1965	19.23
1947	31.53	1966	19.21
1948	30.14	1967	18.72
1949	20.61	1968	16.28
1950	19.93	1969	14.58
1951	18.39	1970	16.79
1952	17.91	1971	17.32
1953	17.70	1972	15.17
1954	15.22	1973	15.71

Apart from somewhat higher values in the 1940s, the statistic remained reasonably constant over the years, bearing out the direct relationship between wetfish landings and number of wetfish vessels fishing.

3.2 b iii Red cod landings (Figs. 22a and b)

Unlike total wetfish landings, there were large fluctuations in the red cod landings from 1936-1973. Relatively large quantities were landed in 1941, 1942, 1966-1970, and in 1973. However in the intervening years, quantities were mainly small. The largest landing for any one year was made in 1967 (1 655.32 t).

These landings were made by a variety of methods (Table 20). However, trawling was the main method of capture. The number of trawlers fishing for wetfish in New Zealand has therefore been included in Table 20 to give a measure of the effort that was used to land red cod. The number for any one year was also divided into the total red cod landings made by trawler for that year to yield the average landing per trawler (or landing/trawler-year).

Table 20: Total red cod landings and percentages taken by the different fishing methods. Also included are the number of trawlers fishing for wetfish in New Zealand, and the average landing per trawler.

Year	Landings (t)	Trawlers (%)	Nets (%)	Lines (%)	Danish Seine (%)	No. of Trawlers	Av. landings per trawler (t)
**							
1936	207.36	44.29	9.28	29.59	17.84	76	1.20
1937	355.60	61.70	8.57	20.11	9.61	90	2.44
1938	380.08	58.03	4.24	28.61	9.11	96	2.30
1939	256.29	72.31	4.56	19.05	4.08	105	1.76
1940	305.36	84.98	2.06	12.34	0.62	101	2.57
1941	624.89	83.41	1.41	12.23	2.95	103	5.06
1942	798.63	81.78	0.39	13.11	4.72	92	7.10
1943	407.06	71.53	1.65	19.13	7.69	106	2.75
1944	321.61	74.10	2.26	19.32	4.33	103	2.31
1945	455.73	89.77	1.79	8.20	0.23	106	3.86
1946	497.64	95.11	0.10	4.64	0.15	121	3.91
1947	417.17	93.67	0.55	5.20	0.58	143	2.73
1948	236.42	92.87	2.57	4.55	-	140	1.57
1949	146.81	97.20	0.07	2.73	-	180	0.79
1950	214.88	97.71	0.11	2.17	-	183	1.15
**							
1951	234.29	98.92	0.06	1.02	-	196	1.18
1952	178.92	97.87	0.45	1.67	-	197	0.89
1953	265.89	98.41	0.34	1.24	-	211	1.24
1954	339.55	97.45	0.75	1.80	-	219	1.51
1955	311.61	99100	0.16	0.84	-	232	1.33
1956	325.12	99.06	0.20	0.74	-	232	1.39
1957	200.56	99.04	0.08	0.88	-	243	0.82
1958	98.09	97.20	0.15	2.64	-	261	0.37

Table 20: Continued

Year	Landings (t)	Trawlers (%)	Nets (%)	Lines (%)	Danish Seine (%)	No. of Trawlers	Av. landings per trawler (t)
1959	133.65	97.87	0.15	1.97	-	293	0.45
1960	226.21	98.29	0.52	1.19	-	247	0.90
1961	242.63	97.28	1.20	1.52	-	250	0.94
1962	301.45	98.40	0.15	1.45	-	263	1.13
1963	320.81	98.91	0.13	0.97	-	297	1.07
1964	454.96	99.30	0.07	0.64	-	271	1.67
1965	524.10	99.38	0.03	0.59	-	293	1.78
1966	824.18	98.67	0.07	1.26	-	339	2.40
1967	1 655.32	99.77	*	0.23	-	356	4.64
1968	858.98	99.76	0.01	0.22	-	363	2.36
1969	576.83	99.66	0.06	0.28	-	350	1.64
1970	759.87	99.31	0.05	0.64	-	382	1.98
1971	393.45	99.55	0.26	0.19	-	413	0.95
1972	300.53	99.70	0.05	0.24	0.02	384	0.78
1973	736.40	99.23	0.04	0.54	0.19	389	1.88

* = rounded off to zero

\- = no recording

** = For the years 1936-1950, many of the trawlers worked only part-time

Nets = set nets and others apart from trawl and seine nets

There was a steady rise in the number of trawlers from 76 in 1936 to 389 in 1973. However, the landings/trawler-year varied in a similar manner to the fluctuations in red cod landings (Figs. 22a and b, Table 20). For example, values coinciding with peak year landings were 5.06 (1941), 7.1 (1942), and 4.64 (1967), compared with values coinciding with small year landings 0.79 (1949), 0.37 (1958), and 0.78 (1972).

It is difficult to find reasons for the fluctuations in size of annual landings. Much speculation is possible with regard to cycles of availability of red cod, biological rhythms etc. (e.g. See Graham, 1953, p. 168). However, factors other than availability play a part in the final analysis of red cod landings. These may be listed as:

(i) Human bias resulting in dumping of catches, even when available (See Section 3.1);

(ii) Dumping of catches when more marketable fish are available;

(iii) The development of market outlets for red cod (See Section 3.1).

3.2 c Red cod landings by area, 1967-1973

3.2 c i Mean red cod landings per day by area

In MAF records, species specific statistics are available on fisheries within geographically distinct fishing areas (Fig. 23). To demonstrate some of the aspects of the red cod fishery by area, statistics were extracted for the period 1967-1973.

The mean daily red cod landings (MDL) for each year by area are shown in Figure 24. Measured as kg/day, the value for any particular year and area was calculated by taking the total quantity of red cod landed and dividing this by the number of days fished. The resulting statistics were comparable from area to area, from year to year.

Red cod were landed in all areas some of the time, and in some areas on all occasions. The highest MDLs were found in areas 13-15 indicating that the red cod fishery is mainly on the East Coast South Island. Considerable MDLs were also registered by areas 7, 8, 16, and 21-23. The other areas maintained low MDLs.

In all areas, there was variation in landing rate from year to year, especially in the main areas (See for example area 13, Fig. 24).

Some comparisons can be made between Figures 24 and 22. For example the sharp fall in the New Zealand red cod landings in 1971 (Fig. 22a) reflected the general fall in MDLs in almost all areas during that year (Fig. 24). A further comparison can be made between these findings and the 1971 figures in Table 20. Although the number of trawlers was high (For role of trawlers in red cod fishery, see Section 3.2 b iii), the landing/trawler-year was low (0.95). That red cod were not available to be caught is indicated.

3.2. c ii Percentages of the New Zealand total red cod landings by area, 1967-1973

This information is presented in Table 21.

FIGURE 23

New Zealand fishing catch areas.

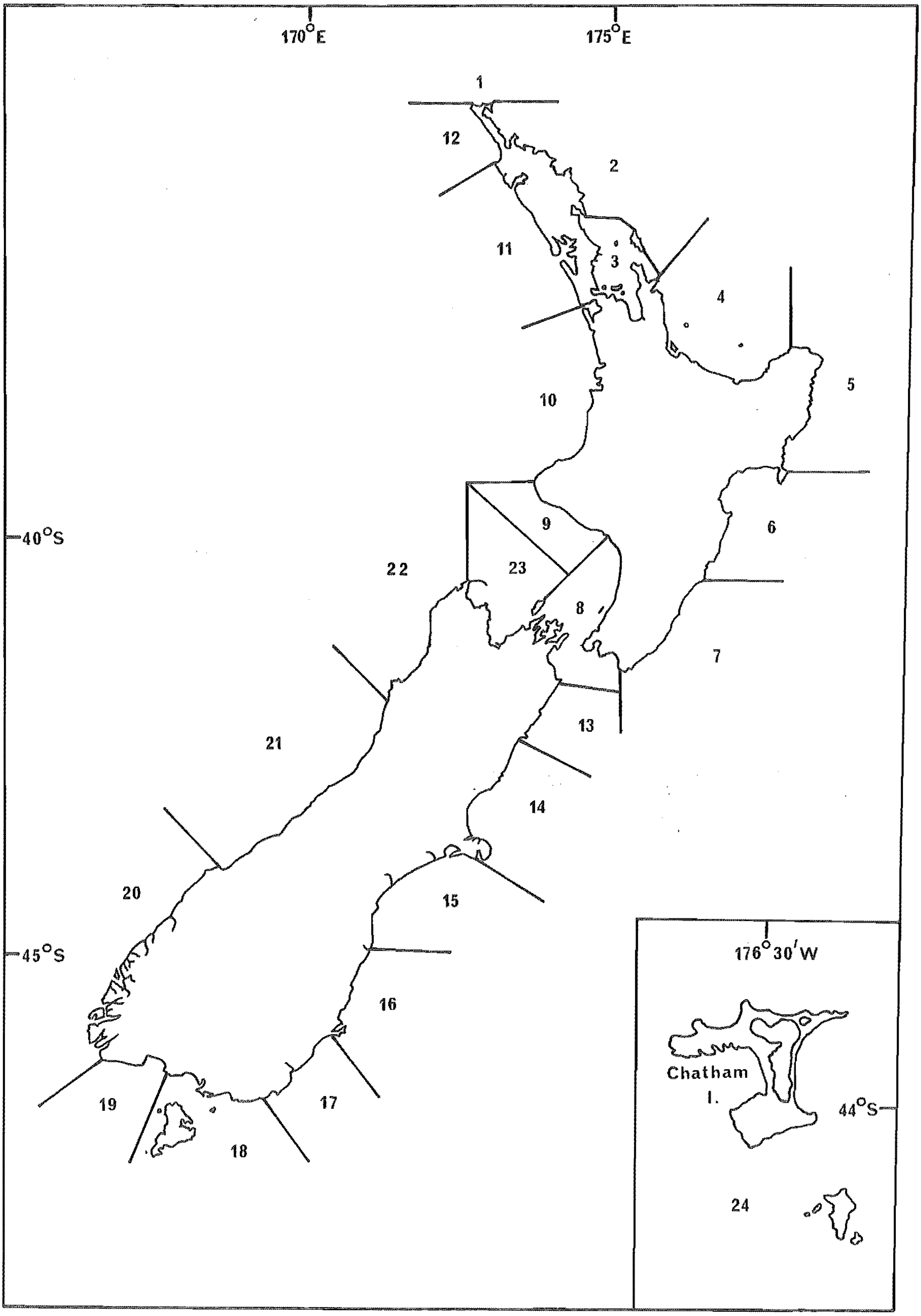

170° E
175° E
40° S
45° S
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
176° 30' W
Chatham I.
44° S
24

FIGURE 24

Mean red cod landings per day by area.

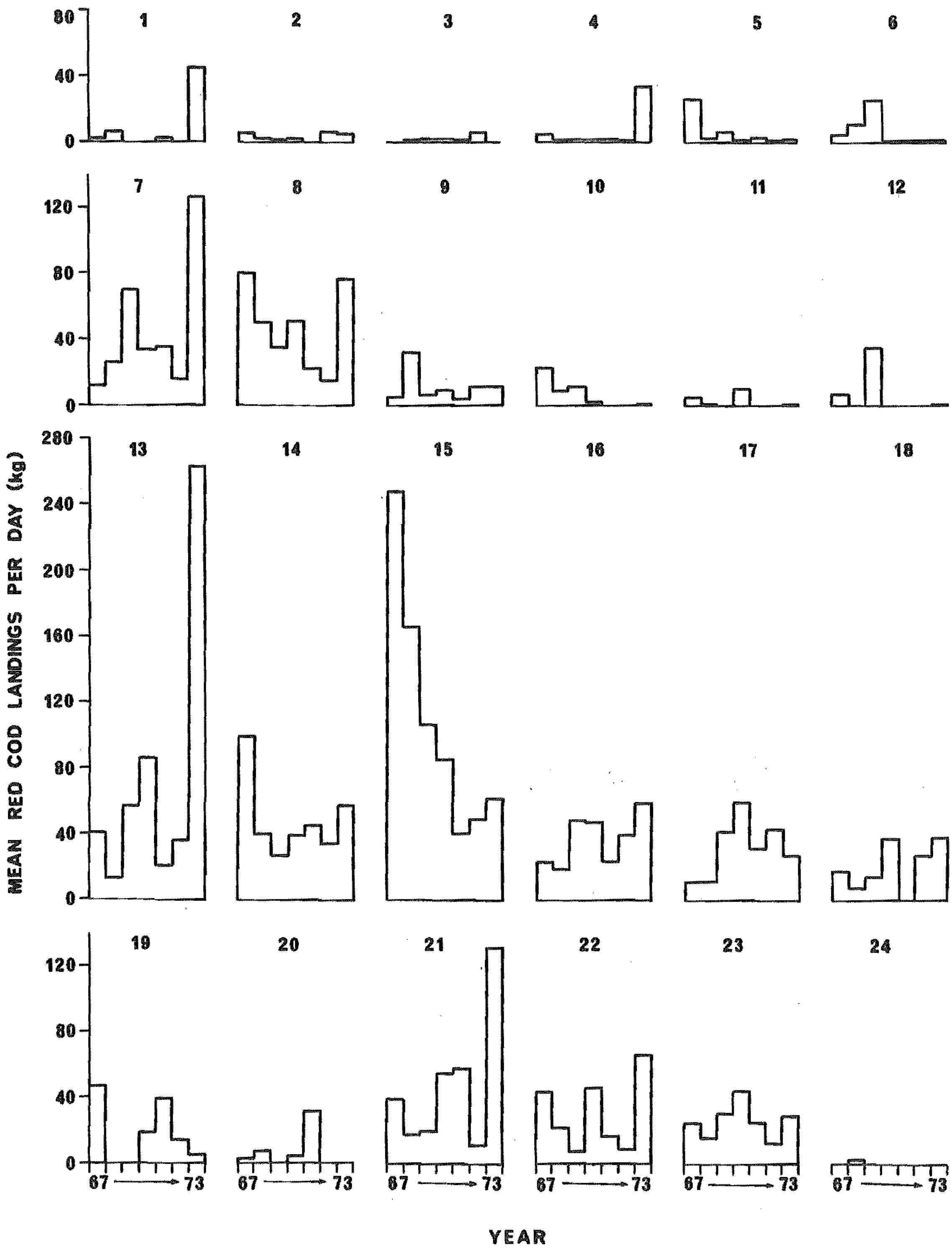

MEAN RED COD LANDINGS PER DAY (kg)
YEAR
67 → 73
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
0
40
80
120
160
200
240
280

Table 21: Area percentages of red cod.

Area	1967	1968	1969	1970	1971	1972	1973
1	0.002	0.011	-	-	0.006	-	0.098
2	0.004	0.011	0.0009	0.003	-	0.161	0.044
3	-	0.007	0.049	0.018	0.002	0.006	0.0006
4	0.004	0.014	0.029	0.019	0.016	0.055	0.106
5	0.750	0.009	0.070	0.005	0.026	0.002	0.002
6	0.098	0.254	2.574	0.008	0.073	0.048	0.019
7	0.138	0.473	1.819	0.359	0.744	0.626	1.526
8	10.100	0.582	6.370	8.837	4.811	3.057	10.039
9	0.008	0.062	0.013	0.030	0.002	0.072	0.076
10	0.068	0.023	0.037	0.008	-	-	0.007
11	0.002	0.001	-	0.051	-	-	0.011
12	0.015	-	0.0007	-	-	-	0.002
13	1.350	0.578	4.044	7.061	1.694	3.500	16.893
14	15.780	10.095	7.847	12.855	27.561	19.972	10.418
15	61.880	74.822	64.495	43.303	40.206	50.251	24.380
16	1.197	1.759	5.749	6.850	7.365	15.070	7.018
17	0.054	0.130	0.938	0.776	1.146	2.681	1.911
18	0.002	0.193	0.366	0.376	0.003	0.380	0.386
19	0.026	-	-	0.247	0.564	0.069	0.066
20	0.002	0.157	-	0.006	0.031	-	-
21	1.737	0.928	0.896	5.465	7.452	1.046	15.599
22	2.485	0.528	0.007	1.719	0.809	0.530	5.813
23	4.290	3.363	4.616	12.003	7.487	2.472	5.583
24	-	0.007	-	-	-	-	-

The trends which were discussed in Section 3.2 c i are mainly substantiated by the percentages of red cod in Table 21. For example, areas 13-15, where the highest MDLs were found (Fig. 24), also recorded high annual percentages of the New Zealand red cod catch. The combined percentages for these three areas were 79.01% (1967), 85.68% (1968), 76.39% (1969), 63.22% (1970), 69.46% (1971), and 73.22% in 1972. There was a noticeable departure from this dominance in 1973. During this year, large increases in landings of red cod were recorded in areas 8 (10.039%) and 21 (15.599%). Other areas which recorded large red cod landings were 16 and 23.

By averaging the 1967-1973 percentages in Table 21 for the main red cod catching areas, the relative importance of each of these areas in the red cod fishery is indicated. Averages by area in decreasing order were are 15 (51.33%), 14 (14.93%), 8 (7.11%), 16 (6.43%), 23 (5.69%), 13 (5.02%), and 21 (4.73%).

3.3 The Lyttelton red cod fishery

3.3 a Introduction

During the period 1970-1973, Mr Eric Midgley of MAF conducted a survey on the trawl catches and landings of the Lyttelton trawler fleet. From the results of this survey, red cod data have been extracted (Table 22).

Part of this thesis is based on samples obtained by the Lyttelton fleet (See Section 1). It was hoped that an analysis of the survey findings would provide information on the red cod fishery in this area to complement the thesis.

Other species of fish such as tarakihi, red gurnard, elephant fish, flounder and smoothhound (for scientific names, see Table 34) were preferentially sought by the Lyttelton trawlers and red cod formed an incidental and small part of most catches (personal observations, and personal communications from Lyttelton trawlermen). For the years 1970-1973, red cod comprised 4.15%, 4.08%, 2.39%, and 3.83% respectively of the wetfish landed at Lyttelton. These percentages should be kept in mind when judging the performance of the Lyttelton trawl fleet on data in Table 22.

The area fished by the Lyttelton trawlers was subdivided as shown in Figure 25. Based on Pegasus Bay in the Canterbury study area (See Section 1), the area fished by Lyttelton trawlers also forms a large part of area 14 (See Section 3.2 c). The major grid squares 1316, 1317, etc. represent thirty minutes of latitude and longitude and each of these was further subdivided into ten minute grids (a to i).

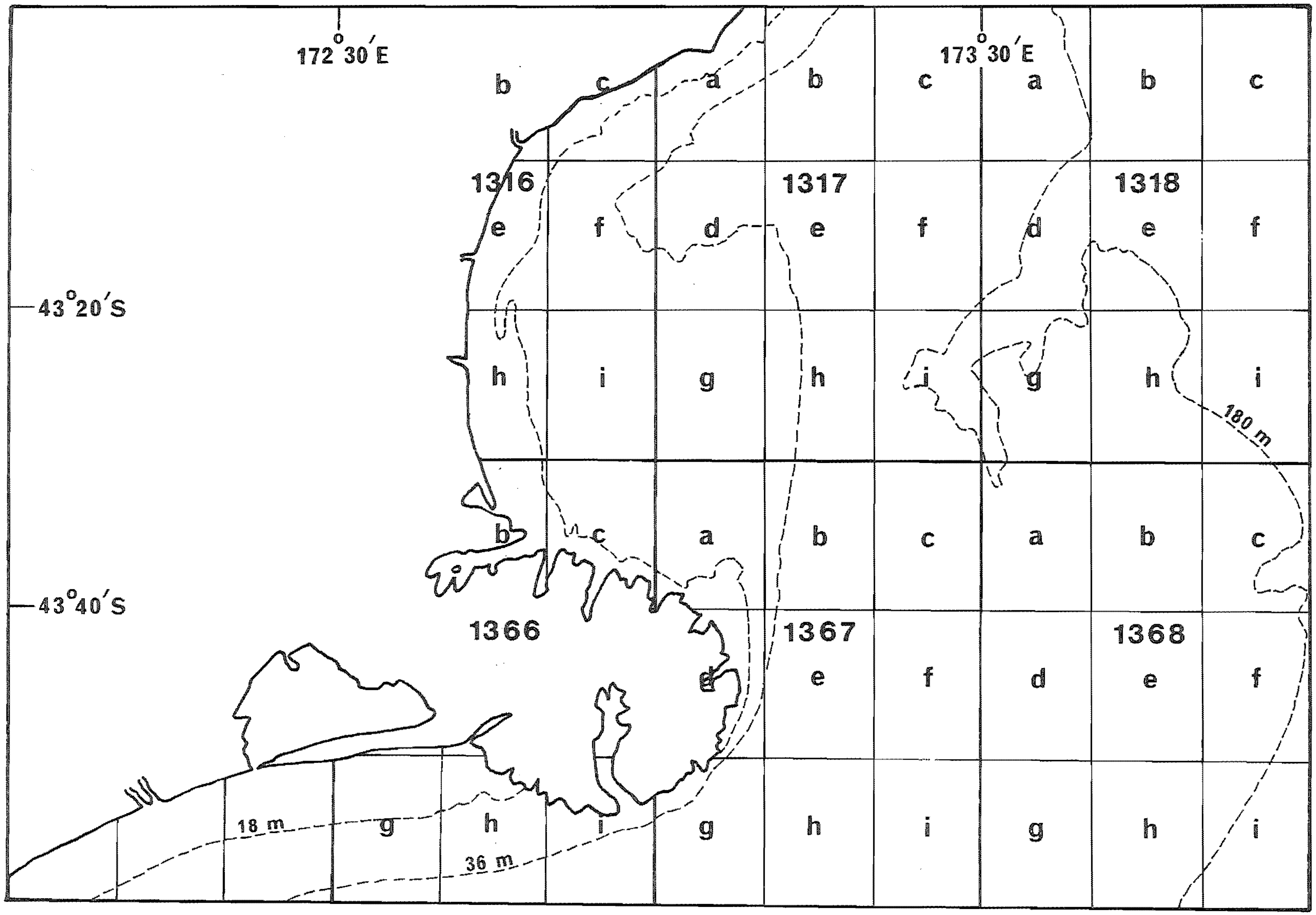
3.3 b Results and discussion

3.3 b i On Table 22

In the above table, the month code is 1-12 representing January - December, and the landing rate is given as cases per hour (cph). Time

FIGURE 25

The area fished by the Lyttelton trawler fleet with subdivisions referred to in text on Lyttelton trawl survey 1970-1973.



172°30′E
173°30′E
43°20′S
43°40′S
1316
1317
1318
1366
1367
1368
a
b
c
d
e
f
g
h
i
18 m
36 m
180 m

Table 22: Red cod landings and landing rates by month by grid in the Lyttelton trawl fishery, 1970-1973.

	1970				1971				1972				1973			
Grid number	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	9.59	1.49	0.16	1	106.74	9.19	0.09	1	11.00	0.75	0.06
									2	23.75	1.49	0.06	2	8.00	0.50	0.06
					3	128.00	34.24	0.27	3	16.50	2.50	0.15				
	4	42.67	5.62	0.13	4	30.00	3.23	0.11								
									5	8.00	0.49	0.06				
1316	6	7.50	1.25	0.17									6	4.50	0.25	0.05
	7	9.25	1.00	0.11												
					9	7.50	0.48	0.06	9	2.00	0.25	0.12				
	10	19.00	1.50	0.08					10							
	11	12.25	2.00	0.16	11	17.50	1.73	0.10	11	9.00	0.50	0.06				
	12	32.50	4.75	0.15	12	82.54	9.11	0.11								
Totals	6	125.17	14.12	0.80	6	275.13	50.28	0.81	7	165.99	14.42	0.54	3	23.50	1.50	0.17

Table 22: Continued

	1970				1971				1972				1973			
Grid number	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	3.00	0.25	0.08	1	6.25	3.50	0.56	1	6.50	0.50	0.07
					2	4.26	1.00	0.24	2	15.50	1.25	0.08				
					3	25.75	12.50	0.53					3	18.25	2.00	0.11
	4	67.17	13.00	0.19	4	50.60	9.49	0.19					4	65.50	13.23	0.20
	5	90.83	39.74	0.44	5	115.93	35.48	0.31	5	10.00	2.75	0.27	5	87.50	34.00	1.37
1317	6	107.27	25.75	0.24	6	37.50	12.00	0.32	6	9.75	0.75	0.08	6	14.75	3.75	0.25
	7	53.25	7.75	0.15	7	136.18	18.60	0.14	7	74.00	5.50	0.07	7	6.75	0.75	0.11
	8	7.00	0.75	0.11	8	52.31	6.34	0.12	8	3.00	0.25	0.08	8	8.00	0.50	0.06
					9	15.02	1.49	0.10					9	4.00	0.25	0.06
	10	7.00	1.00	0.14	10	3.00	0.24	0.08	10	11.00	0.75	0.06	10	4.00	0.50	0.12
	11	44.75	7.50	0.17	11	27.75	2.49	0.09	11	9.00	0.50	0.06				
	12	31.50	3.50	0.11	12	7.00	0.74	0.11	12	14.00	1.50	0.11				
Totals	8	408.77	98.99	1.55	12	476.30	100.62	2.31	9	152.50	16.75	1.43	9	215.25	55.48	1.37

Table 22: Continued

	1970				1971				1972				1973			
Grid number	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	77.25	12.25	0.16	1	17.25	5.50	0.32	1	134.01	39.21	0.29
					2	41.25	5.75	0.14	2	22.75	2.23	0.10	2	25.02	3.24	0.13
					3	83.25	13.25	0.16	3	33.50	3.75	0.12	3	30.75	2.50	0.08
					4	64.16	25.12	0.39	4	84.01	7.74	0.09	4	4.75	0.50	0.10
	5	10.00	0.75	0.07	5	11.00	3.00	0.27	5	3.00	0.25	0.08				
1318	6	11.25	1.25	0.11	6	33.75	22.00	0.65	6	7.00	1.50	0.21				
					7	5.50	0.25	0.05	7	12.50	11.74	0.94				
	8	31.00	5.00	0.16					8	12.00	0.75	0.06				
	9	11.50	2.25	0.20					9	4.25	1.00	0.23				
					10	20.50	3.25	0.16	10	8.50	2.80	0.32	10	18.00	3.50	0.19
	11	4.00	0.50	0.12	11	13.75	1.00	0.07	11	45.75	14.75	0.33				
	12	19.00	5.50	0.29	12	50.75	4.98	0.10	12	25.00	4.25	0.17				
Totals	6	86.75	15.25	0.95	10	401.16	90.85	2.15	12	275.51	56.26	2.96	5	222.53	48.95	0.79

Table 22: Continued

	1970				1971				1972				1973			
Grid number	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	28.38	6.37	0.22	1	161.93	27.73	0.17	1	15.75	1.00	0.06
					2	5.34	0.75	0.14	2	30.92	2.71	0.09				
					3	10.00	1.75	0.17	3	19.58	1.50	0.08				
	4	35.08	2.86	0.08					4	3.50	0.24	0.07				
	5	16.08	2.00	0.12												
1366	6	35.76	3.75	0.11	6	2.25	0.25	0.11								
	10	5.25	0.25	0.04	10	17.25	1.00	0.05								
					11	37.41	3.49	0.09	11	33.50	3.75	0.11				
	12	7.59	2.50	0.33	12	57.92	13.12	0.23								
Totals	5	99.76	11.36	0.68	7	158.55	26.73	1.01	5	249.43	35.93	0.52	1	15.75	1.00	0.06

Table 22: Continued

Grid number	1970				1971				1972				1973			
	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	18.63	13.67	0.74	1	46.00	20.24	0.44	1	22.25	10.75	0.48
					2	73.50	111.00	1.51	2	41.00	6.25	0.15	2	26.00	23.50	0.90
					3	23.50	2.00	0.09	3	3.50	0.25	0.07				
	4	122.08	53.25	0.44	4	15.25	2.73	0.18	4	13.00	2.00	0.15	4	36.00	7.50	0.21
	5	93.76	59.75	0.64	5	31.00	7.50	0.24	5	4.75	0.25	0.05	5	21.00	5.75	0.27
1367	6	31.50	15.00	0.48	6	44.40	0.62	0.01	6	9.50	0.75	0.08	6	3.00	0.50	0.16
	7	24.50	6.00	0.25	7	12.50	1.12	0.09	7	14.50	1.24	0.09	7	3.50	0.25	0.07
	8	7.50	1.50	0.20	8	11.50	0.75	0.07	8	4.00	0.25	0.06	8	8.00	4.50	0.56
	9	4.00	0.25	0.06												
					10	13.50	0.98	0.07								
					11	37.01	6.74	0.18	11	4.00	0.25	0.06				
	12	23.00	10.75	0.47	12	20.50	5.99	0.29	12	22.50	1.50	0.07				
Totals	7	306.34	146.50	2.54	11	301.29	153.10	3.47	10	162.75	32.98	1.22	7	119.75	52.75	2.65

Table 22: Continued

Grid number	1970				1971				1972				1973			
	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h	Month	Time trawled (h)	Number of cases	Cases/h
					1	56.50	9.50	0.17					1	17.00	13.00	0.76
					2	127.26	17.00	0.13	2	45.00	11.75	0.26	2	11.00	1.50	0.13
					3	52.25	7.25	0.14	3	49.33	5.25	0.11	3	5.25	0.50	0.09
	4	42.00	6.25	0.15	4	80.50	16.27	0.20	4	63.01	4.23	0.07	4	19.00	1.50	0.08
	5	44.75	4.00	0.09	5	31.83	5.00	0.16	5	16.00	1.75	0.10				
1368	6	45.75	5.23	0.11	6	50.00	8.00	0.16	6	59.00	8.50	0.14	6	3.00	1.00	0.33
	7	97.00	11.99	0.12	7	60.58	23.23	0.88					7	4.00	1.00	0.25
	8	84.75	14.75	0.23	8	7.51	3.00	0.40	8	25.75	2.00	0.07	8	4.00	0.25	0.06
	9	9.00	7.75	0.86	9	16.75	3.25	0.19					9	21.00	2.75	0.13
	10	11.75	0.75	0.06	10	6.00	2.00	0.33	10	19.50	1.50	0.08	10	10.50	1.50	0.14
	11	5.25	1.00	0.19					11	9.00	1.00	0.11				
	12	15.50	3.50	0.23					12	4.00	2.00	0.50				
Totals	9	355.75	60.22	2.04	10	489.18	94.50	2.26	9	290.59	37.98	1.44	9	94.75	23.00	1.97

trawled is hours fished by a fleet which varied from 15 vessels early in the survey to 3 or 4 towards survey completion. Where no data are listed, red cod were not recorded, although trawling may still have been conducted. Also, as the survey began in April 1970, data were absent for January to March of that year.

In the following discussion, landing rates are referred to particular grids by month by year, abbreviated to GMY. Also, low landing rates refer to the economic aspects of landings (Consider that 3-15 trawlers each manned by 2-3 persons were responsible for making the landings, and also consider that a case of red cod during the survey was worth approximately $8.00).

During the entire period of the survey, red cod landing rates were very low. In only one GMY was more than 1 cph landed. This was for grid 1367, February 1971 when 1.51 cph was landed. Other relatively high landing rates by GMY were 0.94 cph (1318, July, 1972), 0.90 cph (1367, February 1973), and 0.76 (1368, January 1973). Combining grid data by month showed that the highest landing rates occurred in January-March each year.

In terms of number of cases landed, the largest numbers recorded by GMY were 111.00 cases (1367, February 1971), 53.25 cases (1367, April 1970), and 59.75 cases (1367, May 1970).

The data so far show that while landing rates were low, the highest rates occurred in the early months of the year as did the highest number of cases of red cod landed.

3.3 b ii On Table 23

Most trawling occurred in 1971 (2 101.61 h), followed by 1970 (1 380.54 h), 1972 (1 296.77 h), and 1973 (691.53 h). This pattern reflects the rise to a peak in number of trawlers contributing to the survey in 1971 and the subsequent fall in the number to 1973 (personal observations).

Red cod landings varied in a similar manner. Total landings by year were for 1971 (516.08 cases), 1970 (346.44 cases), 1972 (194.32 cases), and 1973 (182.68 cases). Landing rates also decreased in the same order (See Table 23).

Table 23: Further analyses on the data listed in Table 22.

	Grid	1970 Grid totals	1970 % of Grand total	1971 Grid totals	1971 % of Grand total	1972 Grid totals	1972 % of Grand total	1973 Grid totals	1973 % of Grand totals
Time trawled (h)	1316	123.17	8.92	275.13	13.09	165.99	12.80	23.50	3.40
	1317	408.77	29.61	476.30	22.66	152.50	11.76	215.25	31.13
	1318	86.75	6.28	401.16	19.09	275.51	21.25	222.53	32.18
	1366	99.76	7.23	158.55	7.54	249.43	19.23	15.75	2.28
	1367	306.34	22.19	301.29	14.34	162.75	12.55	119.75	17.32
	1368	355.75	25.77	489.18	23.28	290.59	22.41	94.75	13.70
	Average total	230.09	16.66	350.27	16.66	216.13	16.66	115.25	16.66
	Grand total	1 380.54		2 101.61		1 296.77		691.53	
Number of cases of fish	1316	14.12	4.08	50.28	9.74	14.42	7.42	1.50	0.82
	1317	98.99	28.57	100.62	19.50	16.75	8.62	55.48	30.37
	1318	15.25	4.41	90.85	17.60	56.26	28.95	48.95	26.80
	1366	11.36	3.28	26.37	5.11	35.93	18.49	1.00	0.55
	1367	146.50	42.29	153.10	29.67	32.98	16.97	52.75	28.88
	1368	60.22	17.38	94.50	18.31	37.98	19.54	23.00	12.59
	Average total	57.74	16.66	86.01	16.66	32.39	16.66	30.45	16.66
	Grand total	346.44		516.08		194.32		182.68	

Table 23: Continued

	Grid	1970 Grid totals	1970 % of Grand total	1971 Grid totals	1971 % of Grand total	1972 Grid totals	1972 % of Grand total	1973 Grid totals	1973 % of Grand total
Cases/h (cph)	1316	0.80	9.35	0.81	6.74	0.54	6.66	0.17	2.43
	1317	1.55	18.11	2.31	19.23	1.43	17.63	1.37	19.54
	1318	0.95	11.10	2.15	17.90	2.96	36.50	0.79	1.13
	1366	0.68	7.94	0.01	8.41	0.52	6.41	0.06	0.86
	1367	2.54	29.67	3.47	28.89	1.22	15.04	2.65	37.80
	1368	2.04	23.83	2.26	18.82	1.44	17.76	1.97	28.10
	Average total	1.43	16.66	2.01	16.66	1.35	16.66	1.17	16.66
	Grand total	8.56		12.01		8.11		7.01	

The most popular trawl grounds were in grid squares 1317, 1318 and 1368. The percentage of trawling in these grids from 1970-1973 were 61.66%, 65.03%, 55.42% and 77.01% respectively. However, grid 1367 was also popular. Furthermore, it was in this grid that most cases of red cod were caught and the highest landing rates recorded.

In summary therefore, the findings of the survey with regard to the red cod fishery were:

(i) Red cod landing rates were low throughout the period of the survey as were the quantities landed;

(ii) From 1971, there was a decrease in the availability of red cod;

(iii) Most red cod were landed in the early months of the year;

(iv) The largest quantities of red cod were landed from grid 1367, immediately east of Banks Peninsula.

These findings correspond with those of the present author.

3.4 An historical perspective of the Lyttelton red cod fishery

In 1900, Mr L.F. Ayson, Inspector of Fisheries with the Marine Department, conducted a trawling expedition in New Zealand waters. The results are presented in a report (Ayson, 1900). Trawl results with particular reference to Pegasus Bay (See Fig. 25) have been extracted for comparison with some of the results of the 1970-1973 Lyttelton trawl survey.

From 10-19 March 1900, the expedition vessel "DOTO" (28 tons gross register, 20 m overall length), towing a bottom trawl similar to the type used by the Lyttelton trawlers (for dimensions of trawl gear, see Ayson 1900, p. 1), made 19 catches of wetfish in Pegasus Bay. Every catch contained red cod, and in most of the catches, red cod was the principal species. Total effective trawling time was 40.25 h, and the total red cod catch was 9 745.56 kg. This yielded a catch rate of 242.13 kg/h. Note that this is catch rate because quantities of all species caught were recorded.

In March 1971, the Lyttelton trawler fleet fished for 320.75 h in Pegasus Bay and landed 70.99 cases of red cod, or approximately 2 840 kg by weight. This gave a landing rate of 8.85 kg/h. Note that in this case it is landing rate. This is because catches and landings of red cod were not always synonymous owing to this species being dumped at sea as a less desirable portion of the catch.

Allowing that there were probably differences between catch and landing rates, one must still conclude that the red cod fishery in 1900 was much more productive than it was in 1971 in this area.

However, it is possible Ayson's findings were unusual. In 1907, a trawling expedition similar to Ayson's was conducted in New Zealand waters (Waite, 1907). In July of that year, trawling was carried out in Pegasus Bay, and according to Waite, red cod catches were meagre.

3.5 Foreign vessels in relation to the red cod fishery

Vessels from foreign countries periodically visit the waters around New Zealand to fish. These are mainly Russian, Japanese, Taiwanese and Korean vessels.

Information has come to hand from a Japanese source regarding the landings and effort of the Japanese trawl fleet in New Zealand waters (Dr I. Ikeda, Far Seas Fisheries Research Laboratory, Shimuzu, Japan, pers. comm.). For the period 1967-1973, the statistics of numbers of vessels trawling in New Zealand waters, total wetfish landings, and total red cod landings by year are presented in Table 24. Corresponding New Zealand figures are presented for comparison.

Table 24: Trawl data for the Japanese trawler fleet fishing in New Zealand waters, 1967-1973 (Corresponding New Zealand figures in parentheses).

Year	Total wetfish landings (t)	Red cod landings (t)	Percentage red cod	Number of vessels
1967	3 092 (36 283)	126 (1 655)	4.07 (4.57)	2 (1 938)
1968	19 721 (34 165)	365 (859)	1.85 (2.52)	5 (2 099)
1969	25 997 (32 799)	1 172 (577)	4.51 (1.76)	6 (2 250)
1970	31 789 (40 674)	995 (760)	3.13 (1.87)	5 (2 422)
1971	42 212 (44 022)	2 140 (393)	5.07 (0.89)	9 (2 522)
1972	49 133 (40 183)	2 082 (301)	4.24 (0.75)	10 (2 648)
1973	45 602 (44 758)	2 747 (736)	6.02 (1.64)	6 (2 852)

In the 7 years from 1967-1973, the Japanese total wetfish landings increased almost 15-fold while the corresponding New Zealand landings increased just over 1-fold. The Japanese red cod landings also increased markedly (22-fold). However, the New Zealand red cod landings decreased. The percentage of red cod in Japanese landings fluctuated considerably as was the case for New Zealand landings. However, while this species generally became a larger part of Japanese landings, its contribution to the New Zealand wetfish landings declined.

A rough measure of effort used to make the landings is presented in the form of the number of vessels (Table 24). The Japanese vessels landed all fish. However the New Zealand vessels can only be related to the wetfish landings. Many hundreds of these vessels were very small whereas the Japanese vessels were all large (Average of 4 vessels of known weight 2 227 tons). With regard to the New Zealand red cod catch, a better measure of effort is number of trawlers (See Table 20). Effort steadily increased in both fleets from 1967-1973.

From 1971-1973, total wetfish landings were comparable indicating parity in fishing effort. And yet Japanese and New Zealand red cod landings during that time were very different (See Table 24). The Japanese fleet fishes offshore waters while the New Zealand fleet fishes inshore. It is likely that this difference is reflected in the red cod landings in that red cod is distributed more in offshore waters.

That large quantities of red cod occur in offshore waters is supported by catches of Russian vessels (Shuntov, 1970, 1971, and pers. comm.). Up to 10 t have been captured in a one-hour-long trawl.

3.6 Summary

1 Background information on the red cod *Pseudophycis bacchus* in New Zealand waters with comments on its marketability were presented.

2 The red cod fishery in New Zealand was analysed using Ministry of Agriculture and Fisheries (MAF) fish landing statistics for the period 1936-1973. Findings were:

(i) The New Zealand total wetfish landings rose steadily as did the number of vessels fishing. The landings/vessel-year which were derived from these parameters remained constant;

(ii) The New Zealand red cod landings fluctuated considerably. Various possible explanations were advanced for these fluctuations. It could not be established whether fluctuations resulted from changes in abundance of red cod, or from causes internal to the fishery;

and (iii) The worth of red cod in the total wetfish landings varied directly with the quantities landed.

3 The red cod fishery was also analysed using MAF statistics by area for 1967-1973. Red cod were landed from all parts of the New Zealand coast with main landings on the East Coast South Island. Particularly large landings were made in area 15 based on the port of Timaru. For example, 74.82% of the New Zealand red cod catch was landed there in 1968.

4 The Lyttelton red cod fishery was analysed for 1970-1973. Findings were:

(i) Red cod landing rates were low as were the quantities landed;

(ii) From 1971 the availability of red cod decreased;

(iii) Most red cod were landed in the early months of the year;

(iv) The largest quantities of red cod were landed from grid 1367, immediately east of Banks Peninsula.

5 Landings of red cod by the Lyttelton trawler fleet in March 1971 were compared with March 1900 catches made by the expedition vessel "DOTO". The catch rate in 1900 was 242.13 kg/h compared with the 1971 figure of 8.85 kg/h. It is possible the "DOTO" findings were unusual as much smaller red cod catches were made in this area in 1907.

6 New Zealand total wetfish and red cod landings were compared with corresponding Japanese landings for 1967-1973. While both total wetfish and red cod landings increased markedly, the New Zealand wetfish landings increased only slightly and the red cod landings decreased. These differences existed despite parity in fishing effort especially for 1971-1973. It is suggested that the Japanese landed more red cod because this species was available more in the offshore waters where they fish.

SECTION 4

LENGTH FREQUENCY, AGE AND GROWTH

4.1 Introduction

The analysis of length frequency distributions for ageing fish populations was first proposed by Petersen (1894) in his study of the growth of plaice. The method depends on the multimodal nature of length frequency distributions of samples of fish containing more than one age class. It is especially applicable to distributions which represent populations in which there is a single restricted spawning season and rapid and uniform growth. Age classes hatch at about the same time and form approximately normal length frequency distributions. When the length frequency distribution of a sample containing a number of age classes is drawn, a polymodal curve results, the separate modes of which represent the approximate mean sizes of the constituent age classes.

The method has been applied by many workers to age a great variety of fish populations. However, it has its limitations. These can be listed as:

(1) Where the spawning season is not restricted, an age class may be represented by two or more modes.

(2) Where there is slow and/or irregular growth, unpredictable modes of uncertain representation may result.

(3) Where there is selectivity by the fishing gear, length composition of the catch will vary (Lagler, 1968).

(4) Even when the above limitations do not exist, or have been allowed for, the method is usually only able to distinguish the younger age classes. This is because the modes of older fish tend to crowd together and become indistinguishable as their growth rates decrease.

Where length frequency analyses are applicable, they are commonly carried out in conjunction with other methods of ageing such as release and recovery of marked fish, and interpretation of periodic markings on hard parts like scales, otoliths, opercula, vertebrae, fin rays, etc. (Jhingran and Natarajan, 1969). [During this study, I collected otoliths and scales from all red cod which were fully processed (See listing, Tables 5-11, note in Section 1.5 c i). Unfortunately, time did not allow the interpretation of these structures in ageing studies]. In this study, only length frequency distributions were used to study age and growth of red cod populations based on samples taken from various parts of New Zealand (See Section 1). The length frequency distributions for male and female fish were almost identical. Therefore, results for both sexes were combined.

4.2 Materials and Methods

4.2 a Sample representativeness

Methods of sampling, catch data, and catch processing are presented and discussed in Section 1.5. Selectivity in relation to obtaining the samples is also discussed. Little was done to estimate selectivity in this study although it doubtless occurred. As Lagler (1968) stated, "... most fishing operations are selective...". An obvious source of selectivity was the different gear construction and codend mesh sizes used on commercial vessels compared with the research vessel "James Cook" (See Section 1). Nevertheless, all samples were processed in a similar manner, bearing in mind the selectivity factors.

4.2 b Length frequency, age and growth

Most samples taken were measured for length frequency. Additional length frequency data which were collected by Dr D. Eggleston of FRD are also presented. Where modes in the length frequencies were obvious, and reasonably discreet, their length limits, means, and standard deviations were calculated using probability paper (Buchanan-Wollaston and Hodgson, 1929; Harding, 1949; Cassie, 1950, 1954; Tanaka, 1962; Harris, 1968). This technique, which separates a polymodal length frequency curve into its normal components, has greatly increased the usefulness of length frequency analyses.

For some of the Canterbury samples, there were sufficient clear modes to allow tentative estimates of age and growth for the younger age classes in the population.

4.2 c Length-weight relationship

Samples were also weighed so that the length-weight relationship could be derived. Because this relationship has been found to vary with season (largely due to changes in gonad weight) and with time of day (because of changes in stomach fullness), the gutted body weight, that is, the weight minus the gonads and alimentary tract, was used. No differences were found between males and females. All fish were therefore analysed together.

Although samples were obtained from many sources (See Section 1), the composition of the samples used in length-weight analyses was relatively constant. Each sample consisted of as wide a range of lengths and weights of fish as possible.

For most fish the length-weight relationship can adequately be described by the equation:

$$w = a\ l^{b}$$

where w = weight, l = length, a is a constant and b an exponent with a value nearly always between 2 and 4, often close to 3 (Le Cren, 1951; Tesch, 1968). In this study, length-weight relationships were calculated in the logarithmic form of the above equation, i.e.

$$\log w = a + b \log l$$

The regression lines were fitted by the method of least squares (See Sokal and Rohlf, 1969, Ch. 14). The regression coefficient, or slope of the line is b, while a represents the intercept of the line with the Y-axis.

The value b has been observed to indicate different types of growth. When it is 3, it describes what Le Cren called the ideal fish, one which grows isometrically. This has been observed occasionally (Allen, 1938; Kohler, 1959; Smith and Kramer, 1964; Staples, 1972). When b is greater than 3, as was found by Keys (1928), Mraz (1964), Frost and Kipling (1967), Hart (1967), Carter (1968), Halliday (1969a), and Baker (1972), allometric growth is indicated, the fish becoming heavier in relation to length. A b value of less than 3, where fish are lighter for their length, has also been found (Beardsley and Richards, 1970; Habib, 1971).

There is therefore variation in b from species to species. Variation can also be expected, within a species, for fish from different areas, of different sexes, or for larval, immature and mature fish. However, if the composition of samples is constant, b values will often remain fairly similar throughout a year.

The above causes of variation in b, also apply to a values. In addition, a "... will often vary seasonally, with the time of day, and between one habitat and another" (Tesch, 1968).

FIGURE 26

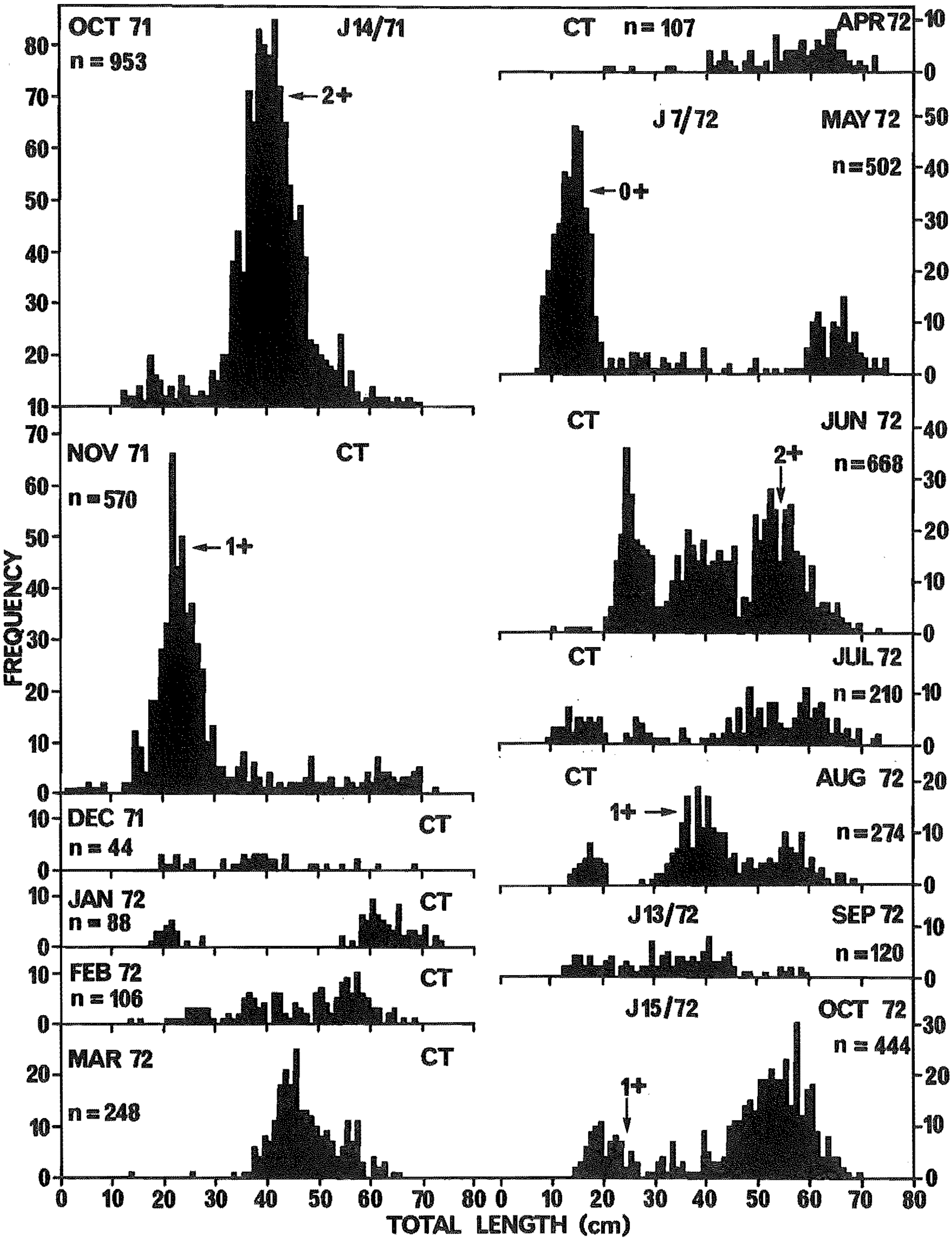
Canterbury length frequency distributions for October 1971 - October 1972. For the following modes (See Fig.), the number of fish (n), mean ($\bar{x}$), and standard deviation (s) were calculated using probability paper. An age class was also allocated.

1971

October	-	2+,	$n = 816$,	$\bar{x} = 40.9$ cm,	$s = 5.9$ cm
November	-	1+,	$n = 409$,	$\bar{x} = 22.0$ cm,	$s = 3.4$ cm

1972

May	-	0+,	$n = 346$,	$\bar{x} = 13.8$ cm,	$s = 3.0$ cm
June	-	2+,	$n = 248$,	$\bar{x} = 54.0$ cm,	$s = 4.0$ cm
August	-	0+,	$n = 36$,	$\bar{x} = 17.4$ cm,	$s = 2.2$ cm
	-	1+,	$n = 164$,	$\bar{x} = 39.5$ cm,	$s = 4.3$ cm
October	-	1+,	$n = 77$,	$\bar{x} = 20.3$ cm,	$s = 3.1$ cm



OCT 71
n = 953
J14/71
2+
NOV 71
n = 570
CT
1+
DEC 71
n = 44
CT
JAN 72
n = 88
CT
FEB 72
n = 106
CT
MAR 72
n = 248
CT
CT
n = 107
APR 72
J7/72
MAY 72
n = 502
0+
CT
JUN 72
2+
n = 668
CT
JUL 72
n = 210
CT
AUG 72
1+
n = 274
J13/72
SEP 72
n = 120
J15/72
OCT 72
n = 444
1+
FREQUENCY
TOTAL LENGTH (cm)

Data on lengths and weights of fish have commonly been analysed to yield biological information. However, there has often been confusion regarding the aims of such analyses. Le Cren (1951) described the two different objectives which workers have sought in length-weight analyses as:

(1) the description of the mathematical relationship between length and weight, primarily so that one may be converted into the other, and

(2) the measurement of the variation from the expected weight for length of individual fish, or groups of individuals, as indications of fatness, general "well-being", gonad development, etc., generally referred to as "condition".

Only the former objective is discussed in this section. The latter is discussed in Section 6.

4.3 Results and Discussion

4.3 a Length frequencies

4.3 a i Canterbury length frequencies, age and growth

Monthly length frequency distributions for October 1971 - October 1972 are presented in Figure 26. A total of 4 384 red cod were measured from this area during this period. As is indicated in the figure, samples were either collected by the "James Cook" (station numbers given), or by commercial trawlers (CT - See Table 4, and 1.5 c).

Few of the distributions were suitable for further analyses. However, relatively discreet modes were present in the October and November 1971 samples, and in the May, June, August, and October samples for 1972. Statistical parameters for the modes, which are indicated in Figure 26, are presented in the caption for this figure.

To interpret the above modes, information is needed on time of spawning, and on the duration of the egg and larval phases of the life history.

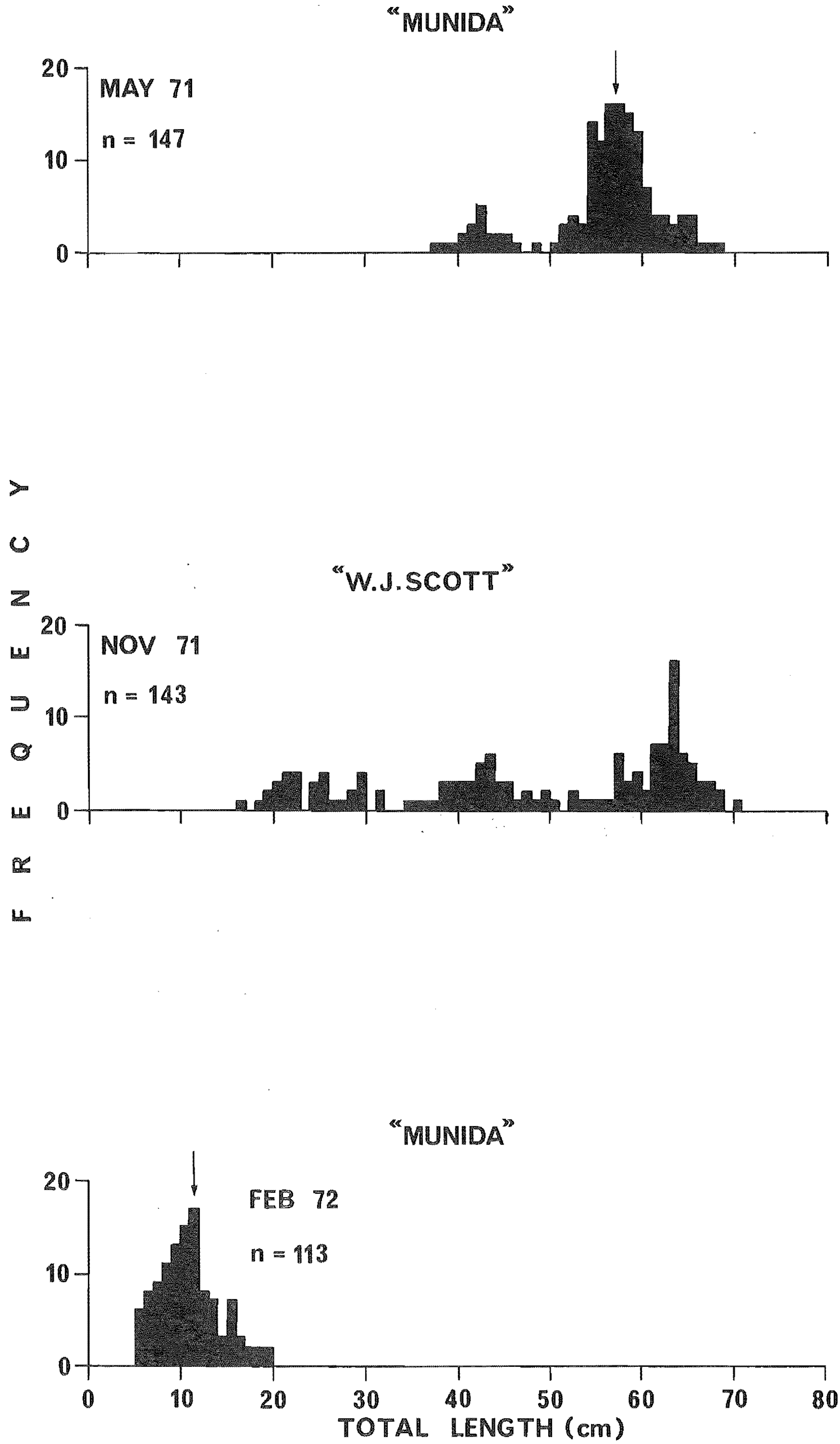
Spawning takes place from August to October in the Canterbury area with peak spawning in August and September. September can be taken as the appropriate birth-month (See Section 6).

No information is available on the eggs and larval stages,

FIGURE 27

Otago length frequency distributions with probability paper analyses of modes indicated in figure.

May 1971	February 1972
n = 100	n = 109
$\bar{x}$ = 57.3 cm	$\bar{x}$ = 10.4 cm
s = 2.3	s = 3.0


"MUNIDA"
MAY 71
n = 147
"W.J.SCOTT"
NOV 71
n = 143
"MUNIDA"
FEB 72
n = 113
FREQUENCY
0
10
20
30
40
50
60
70
80
TOTAL LENGTH (cm)

although small red cod (average total length for 10 fish 3.4 cm, smallest 1.7 cm) were collected in November 1971. If it can be assumed that the duration of the egg and larval phase is similar to that of many Northern Hemisphere cods, that is, about six weeks (Sars, 1879; Burd and Jones, 1948; Breder and Rosen, 1966), then these small red cod probably resulted from the most recent spawning.

Extending this reasoning, the mode for May 1972 would represent fish still in their first year of life (0+ age class), and similarly for the 0+ fish of August 1972. With the birth month being September, the mode for November 1971 probably represented fish which had recently entered their second year of life (1+). Discounting the year of sampling, a growth rate of about 20 cm in length in the first year is indicated. This reasoning is supported by Graham (1953). Also, a similar growth rate was found for the closely related *Pseudophycis barbatus* in Tasmanian waters (Walker, 1972). He found the *P. barbatus* grew about 18 cm in its first year of life.

Regarding growth rate in subsequent years, results are scanty. However, once again discounting the year of sampling, speculation is possible.

For 1+ fish, indications are that rapid growth continues. In October, the mean length for this age class was 20.3 cm, and in November, 22.0 cm. This rate can be projected to what is possibly also a 1+ mode in August and on to the inchoate 2+ age class of October. This 20 cm of growth in the second year is not unusual for codfishes (See Walker, 1972, Fig. 8).

Any further speculation would be pointless, based on the available data. Further work based on my otolith and scale collections is necessary to complement the above observations on length frequencies.

4.3 a ii Otago length frequencies

Length frequencies for May and November 1971, and for February 1972, are presented in Figure 27. A total of 403 fish were measured, samples being taken by the research vessels "Munida" and W.J. Scott". Probability paper analyses were carried out on the modes indicated in the figure. Results are on the caption page for this figure.

The November 1971 sample was the only one in which the entire size range of red cod was sampled. Unfortunately, there were no clear

FIGURE 28a

Foveaux Strait length frequency distribution. Probability paper analysis of indicated mode yielded the statistics:

$n = 111$

$\bar{x} = 62.4$ cm

$s = 3.5$

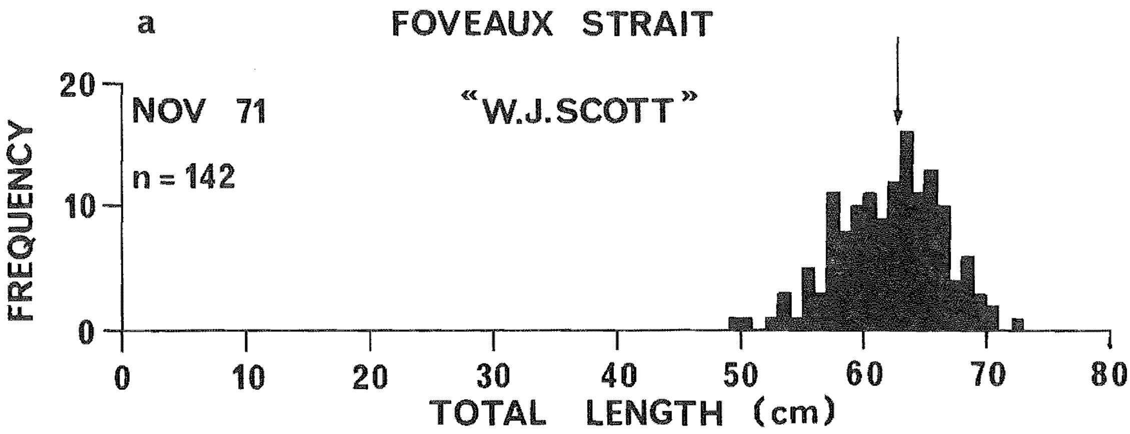
FIGURE 28b

W.C.S.I. length frequency distribution. Statistics for indicated mode were:

$n = 162$

$\bar{x} = 25.6$ cm

$s = 2.4$


a
FOVEAUX STRAIT
NOV 71
"W.J.SCOTT"
n = 142
FREQUENCY
0
10
20
30
40
50
60
70
80
TOTAL LENGTH (cm)

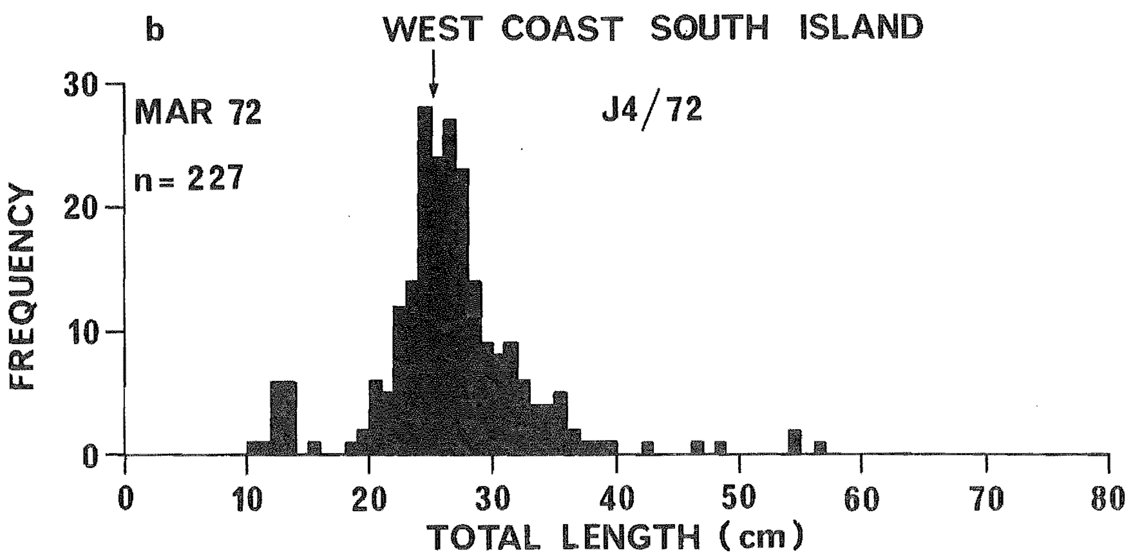
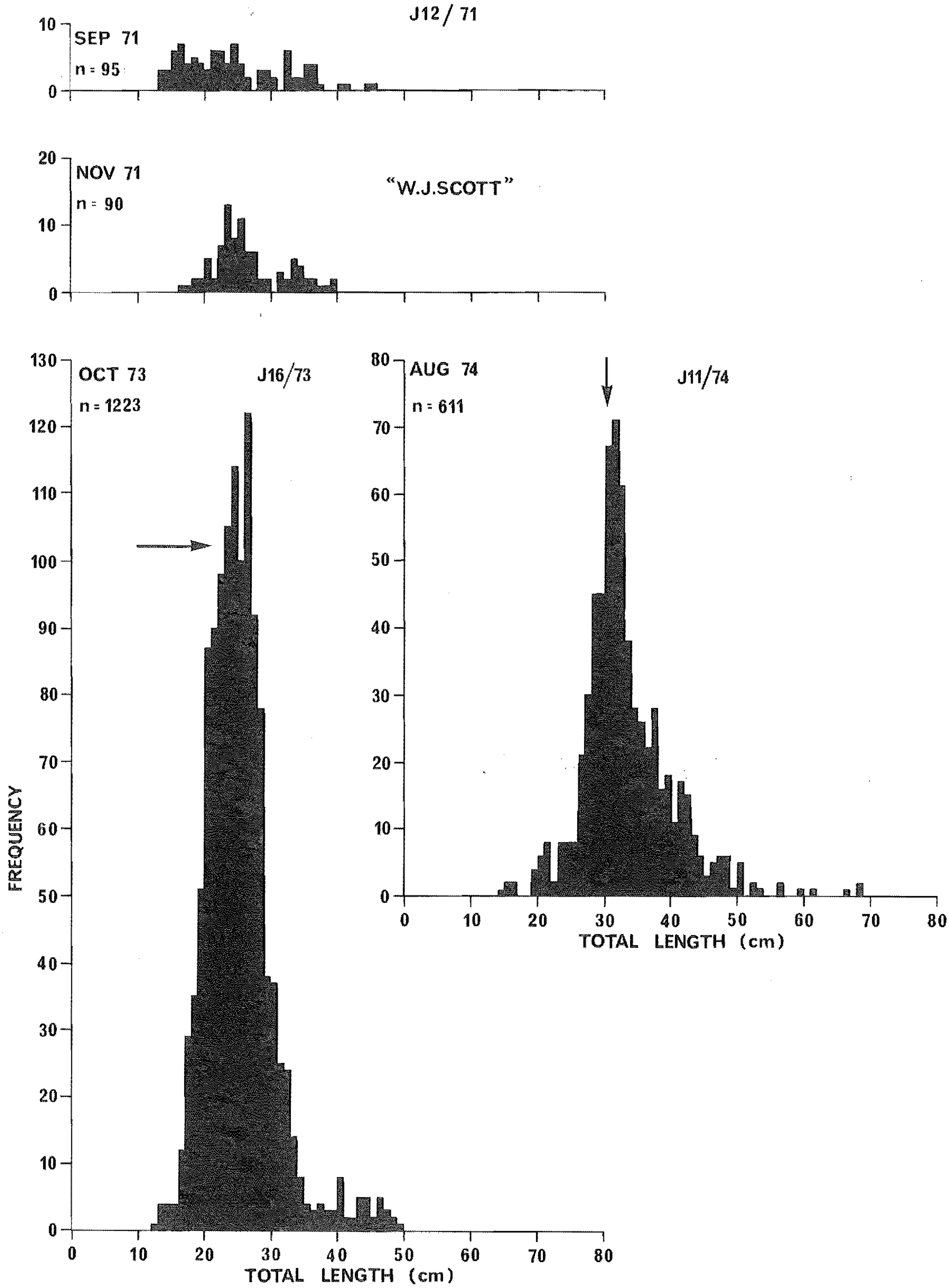

b
WEST COAST SOUTH ISLAND
MAR 72
J4/72
n = 227
FREQUENCY
0
10
20
30
40
50
60
70
80
TOTAL LENGTH (cm)

FIGURE 29

W.C.N.I. length frequency distributions. Statistics for indicated modes are:

October 1973	August 1974
n = 1 175	n = 576
$\bar{x}$ = 24.6 cm	$\bar{x}$ = 31.5 cm
s = 3.5	s = 3.7


J12/71
SEP 71
n = 95
NOV 71
n = 90
"W.J.SCOTT"
OCT 73
n = 1223
J16/73
AUG 74
n = 611
J11/74
FREQUENCY
TOTAL LENGTH (cm)
TOTAL LENGTH (cm)

modes. The May 1971 sample was biased towards big fish. The clear mode analysed can possibly be equated with a similar mode for June 1972 from the Canterbury area (See above). Similarly, the mode analysed for February 1972 may represent the same age class as is depicted by the Canterbury area May 0+ mode.

4.3 a iii Foveaux Strait length frequency

The length frequency distribution for this area for November 1971 is presented in Figure 28a. This sample, which was taken by the "W.J. Scott", was strongly biased towards larger fish, the mean length of which was 62.4 cm (s = 3.5).

4.3 a iv W.C.S.I. length frequency

This is presented in Figure 28b. In March 1972, 227 red cod were measured from this area from "James Cook" catches. Statistics for the most obvious mode are presented in the caption to this figure. If there is any correspondence between East and West Coast South Island red cod populations, this mode probably represents fish of age 1+ (See caption to Fig. 26).

4.3 a v W.C.N.I. length frequencies

Length frequencies for September and November, 1971, October 1973, and August 1974 (the last two recorded by Dr D. Eggleston of FRD), are presented in Figure 29. The November sample was taken by the "W.J. Scott", and the others by the "James Cook".

Most of the 2 019 fish measured were found in the modes indicated in the October 1973 and August 1974 histograms. Statistical parameters for these modes are indicated in the caption to Figure 29. Analyses on the other histograms were not carried out as no clear modes were present.

The October mode probably represented 1+ fish corresponding to the same age group for October and November samples in the Canterbury area. However, the August 1974 mode is inexplicable. There appears to have been no corresponding mode in any of the other length frequencies. Until further samples are taken and the age and growth of the various red cod populations ascertained, this mode remains unexplained.

FIGURE 30a

C.B.C.C. length frequency distributions for February, May and September, 1972. The February sample was taken by commercial trawler (CT), the May and September samples by the "James Cook". Statistics gained from probability paper analysis of the mode indicated in the May sample were:

$n = 781$

$\bar{x} = 13.7$ cm

$s = 2.0$

FIGURE 30b

East Cape length frequency distribution for July 1973. Sample taken by the "James Cook".

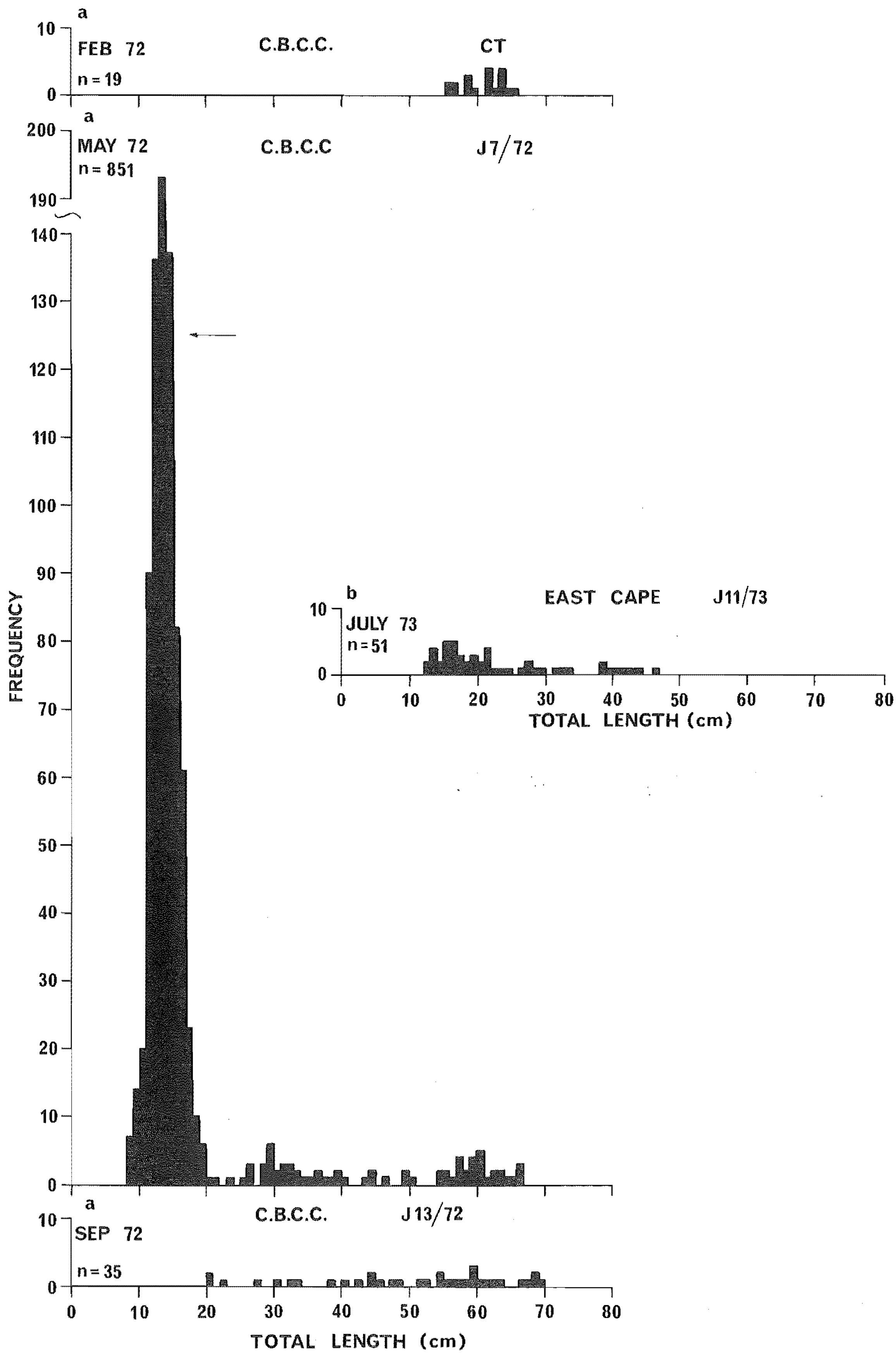

a
FEB 72
n = 19
C.B.C.C.
CT
a
MAY 72
n = 851
C.B.C.C
J7/72
b
JULY 73
n = 51
EAST CAPE
J11/73
TOTAL LENGTH (cm)
a
SEP 72
n = 35
C.B.C.C.
J13/72
FREQUENCY
TOTAL LENGTH (cm)

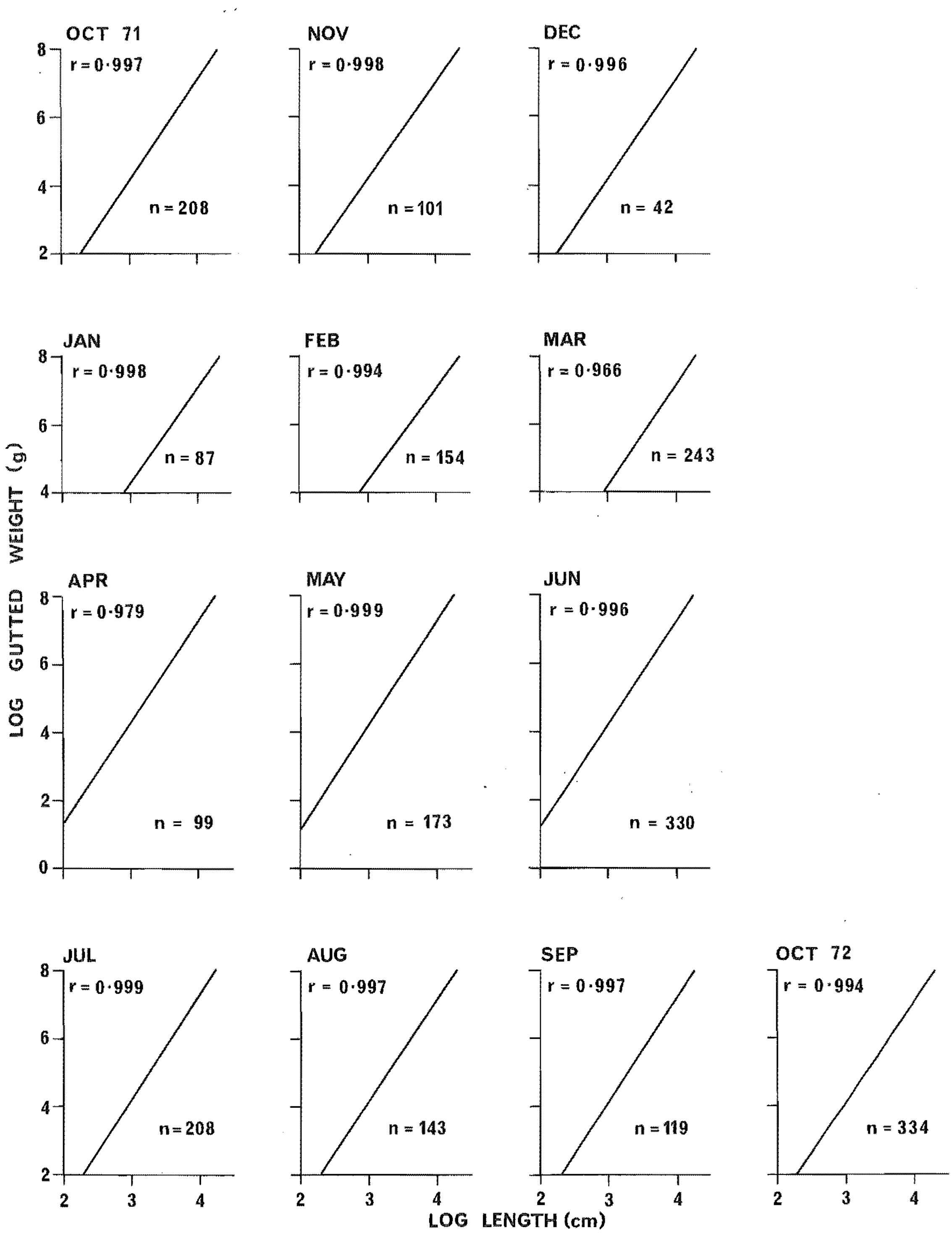
FIGURE 31

Length-weight relationships for red cod samples from the Canterbury area.

1971	
October	log w = -4.593 + 2.905 log 1
November	" = -4.562 + 2.913 "
December	" = -4.621 + 2.903 "
1972	
January	" = -4.344 + *2.878 "
February	" = -4.683 + 2.948 "
March	" = -4.521 + 2.915 "
April	" = -5.052 + 3.057 "
May	" = -5.023 + 3.068 "
June	" = -4.832 + 3.011 "
July	" = -4.972 + 3.050 "
August	" = -4.829 + 2.996 "
September	" = -4.618 + 2.922 "
October	' = -4.898 + 3.005 "

NB: All correlation coefficients (r) significant at 1% level.

* Significant deviation from 3 at 5% level.


OCT 71
r = 0·997
n = 208
NOV
r = 0·998
n = 101
DEC
r = 0·996
n = 42
JAN
r = 0·998
n = 87
FEB
r = 0·994
n = 154
MAR
r = 0·966
n = 243
APR
r = 0·979
n = 99
MAY
r = 0·999
n = 173
JUN
r = 0·996
n = 330
JUL
r = 0·999
n = 208
AUG
r = 0·997
n = 143
SEP
r = 0·997
n = 119
OCT 72
r = 0·994
n = 334
LOG GUTTED WEIGHT (g)
LOG LENGTH (cm)
0
2
3
4
6
8

4.3 a vi C.B.C.C. length frequencies

These are presented in Figure 30a. The only sample which warranted further analysis was that for May 1972. This distribution showed a very prominent mode with a mean value of 13.7 cm (s = 2.0). This almost certainly corresponded with the 0+ mode for the May 1972 Canterbury sample (Fig. 26). On the basis of this, it is possible that the red cod populations in these two areas are little different in terms of recruitment of fish into the population and growth.

4.3 a vii East Cape length frequency

This is presented in Figure 30b. Red cod were scarce in this area during July 1973. Only 51 fish were caught in 31 h of trawling by the "James Cook". Most fish were small, the mean total length being 20.7 cm. Red cod are rarely found in the region of East Cape, and when found, are usually small in size (C.M. Vooren, pers. comm.).

4.3 b Length-weight relationships

4.3 b i Canterbury length-weight relationships (Fig. 31)

There were small variations in both a and b values. As was pointed out in Section 4.2 c, the samples used in this study were relatively constant. Therefore, b values might have been expected to remain fairly similar throughout the samples. This was in fact the case. In only one sample (January, 1972) did b differ significantly from 3. The b value of 2.878 for this month indicated that red cod in this sample were lighter in relation to their length than would be expected if they were growing isometrically. This could be related to the low level of feeding registered by this sample (It had the lowest stomach fullness index of all samples - see Fig. 46). In all other samples, the relationship between length and weight was isometric.

To establish the degrees of relationship between the regression lines in Figure 31, the equations of 23 pairs of regressions were compared using analysis of covariance. Testing was undertaken in three stages, conditionally:

(1) Bartlett's test of homogeneity of variances was applied (See Sokal and Rohlf, 1969, pp. 369-375) which tested for homogeneity of variances of the samples. If the χ^2 values generated indicated

Table 25: Analysis of covariance of combinations of red cod total length-gutted weight regressions, Canterbury samples. (Key to numbers in comparative combinations: 1-13 = October 1971 - October 1972; for all testing, P < 0.01.)

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Common Regression a	Common Regression b
1 + 2	√	3.93606	√	0.12825	√	0.10034	-4.580	2.917
1 + 3	√	0.68408	√	0.44996	√	0.23953	-4.594	2.921
1 + 4	√	0.52096	√	2.89468	x			
1 + 5	x		x		x			
1 + 6	√	3.55128	√	0.13602	x			
1 + 7	√	1.22388	√	4.89983	x			
1 + 8	√	0.11928	x		x			
1 + 9	√	3.34712	x		x			
1 + 10	√	0.19209	x		x			
1 + 11	x		x		x			
1 + 12	√	0.10945	√	0.34320	√	3.86197	-4.620	2.926
1 + 13	√	3.97705	x		x			
2 + 3	x		x		x			
3 + 4	√	0.50074	√	0.38064	√	2.99991	91.576	2.514
4 + 5	x		x		x			
5 + 6	√	1.80946	√	0.36943	x			
6 + 7	√	0.13715	√	3.01363	x			
7 + 8	√	1.83511	√	0.33637	x			
8 + 9	√	1.80497	x		x			
9 + 10	√	5.39695	√	4.38584	√	0.48782	-4.930	3.038
10 + 11	x		x		x			
11 + 12	x		x		x			
12 + 13	√	2.30984	x		x			

FIGURE 32

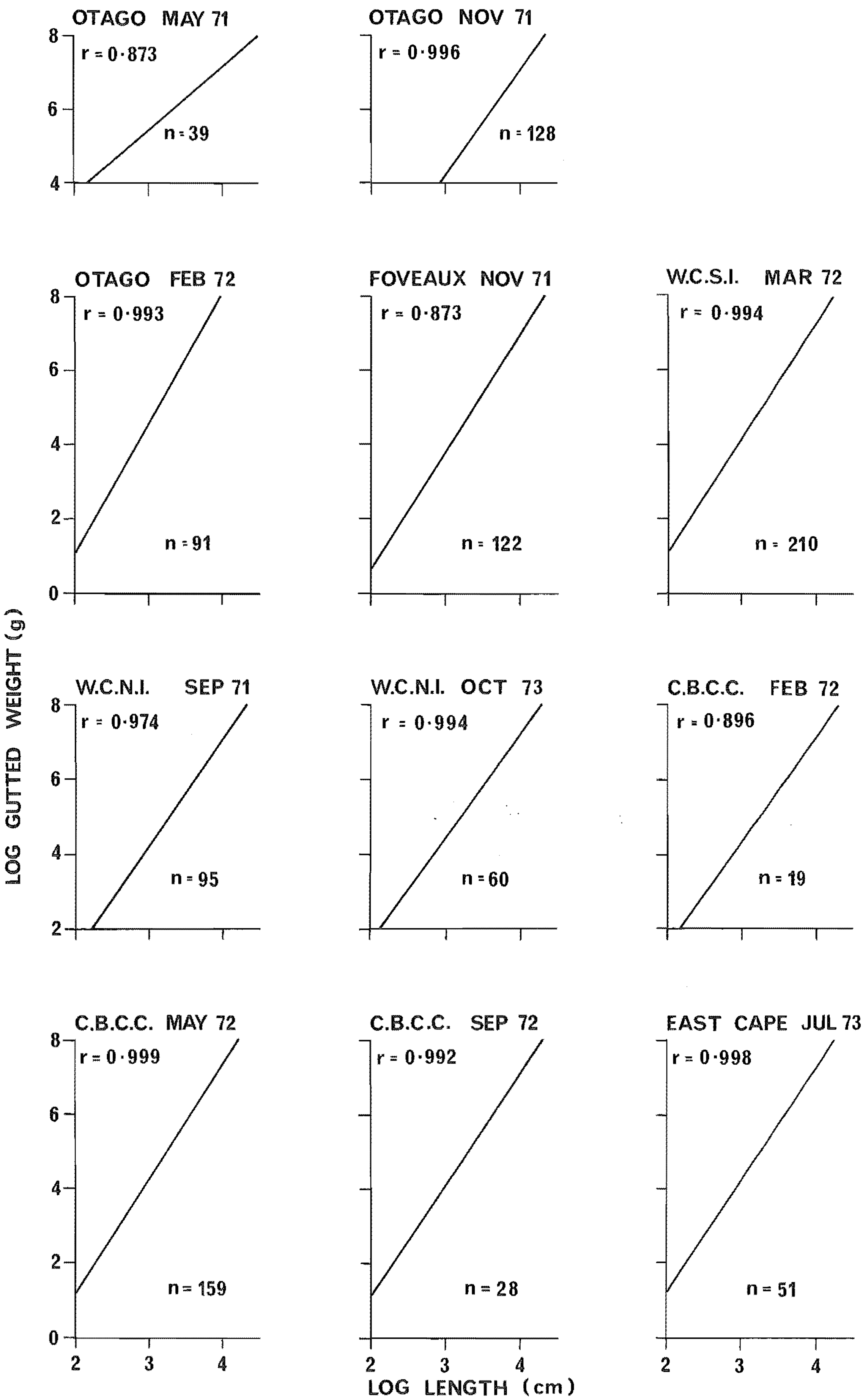
Length-weight relationships for red cod samples from other areas (Equations as for Fig. 31, but only a and b values given).

	a	b
OTAGO		
May 1971	0.289	1.721**
November 1971	-4.452	2.887*
February 1972	-5.533	3.335**
FOVEAUX STRAIT		
November 1971	-4.176	2.802**
W.C.S.I.		
March 1972	-5.152	3.111*
W.C.N.I.		
September 1971	-4.402	2.859**
October 1973	-4.005	2.804**
C.B.C.C.		
February 1972	-3.315	2.631**
May 1972	-5.049	3.090
September 1972	-5.066	3.042
EAST CAPE		
July 1973	-4.953	3.064

NB: All r values significant at 1% level.

* Significant deviation from 3 at 5% level.

** Significant deviation from 3 at 1% level.



OTAGO MAY 71
r = 0·873
n = 39
OTAGO NOV 71
r = 0·996
n = 128
OTAGO FEB 72
r = 0·993
n = 91
FOVEAUX NOV 71
r = 0·873
n = 122
W.C.S.I. MAR 72
r = 0·994
n = 210
W.C.N.I. SEP 71
r = 0·974
n = 95
W.C.N.I. OCT 73
r = 0·994
n = 60
C.B.C.C. FEB 72
r = 0·896
n = 19
C.B.C.C. MAY 72
r = 0·999
n = 159
C.B.C.C. SEP 72
r = 0·992
n = 28
EAST CAPE JUL 73
r = 0·998
n = 51
LOG GUTTED WEIGHT (g)
LOG LENGTH (cm)

that the variances were sufficiently homogeneous,

(2) The slopes were compared, F values being generated. If the slopes did not differ significantly, according to the F-test,

(3) An F-test determined the degree of agreement between intercepts. If they did not differ significantly, a regression coefficient for the combined samples was computed.

Testing was discontinued if either the χ^2 or F-tests indicated that the samples being tested differed significantly.

Results are presented in Table 25. In 17 of the 23 comparisons, the variances were homogeneous. In 11 of these, the slopes did not differ significantly. And in 5 of these comparisons, neither did the intercepts differ significantly. For these 5, regression equations for the combined samples were computed.

The monthly pairs which were most similar were October and November 1971, October and December 1971, October 1971 and September 1972, December 1971 and January 1972, and June and July 1972.

The above analyses isolated two categories of samples based on their length-weight relationships. These were:

(1) The spring-early summer samples (for the months September - December),

and (2) the winter samples (June-July).

For the first category the common regression for October - November 1971 (Table 25) adequately describes the length-weight relationship of this season. For the second category, the common regression for June - July 1972 in Table 25 is adequate. For all other samples, the regression equations as presented in Figure 31 could be used to describe the length-weight relationships of red cod in Canterbury waters.

4.3 b ii Other areas length-weight relationships (Fig. 32)

Unlike the Canterbury samples, a and b values in these samples varied considerably. For example, b ranged from an inordinately low 1.721 (Otago, May 1971), to a high of 2.335 (Otago, February 1972). In 8 of the 11 samples, b was significantly different from 3. In 6 of these samples, the differences were at the 0.01 probability level.

It is probable that much of the variation in b was due to differences in the composition of the samples. For example, the mean

Table 26: Analysis of covariance of combinations of red cod total length-gutted weight regressions, other areas samples, as well as Canterbury samples. (Key to numbers in comparative combinations: 1-13 = October 1971 - October 1972, Canterbury samples; 14-16 = Otago samples May and November 1971, and February 1972; 17 = Foveaux Strait sample; 18 = W.C.S.I. sample; 19-20 = September and October W.C.N.I. samples; 21-23 = February, May and September C.B.C.C. samples; and 24 = East Cape sample. For all testing, $P < 0.01$.)

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Common regression a	b
14 + 15	√	0.46927	x		x			
14 + 16	√	1.4952	x		x			
15 + 16	√	0.37375	x		x			
14, 15, 16	√	1.20142	x		x			
19 + 20	x		x		x			
21 + 22	√	0.51481	√	1.93496	x			
21 + 23	√	0.94969	√	1.21015	√	5.31415	-5.263	3.097
22 + 23	√	1.55158	√	0.50359	x			
21, 22, 23	√	1.69773	√	1.16494	x			
1 + 20	√	1.15551	x		x			
13 + 20	√	0.68664	x		x			
1, 13, 20	√	4.13743	x		x			
2 + 15	x		x		x			
2 + 17	x		x		x			
15 + 17	√	0.03481	√	0.35421	x			

Table 26: Continued

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Common regression a	b
2, 15, 17	x		x		x			
5 + 16	√	2.92907	x		x			
5 + 21	√	1.72160	√	0.62009	x			
16 + 21	√	4.00401	√	2.32773	x			
5, 16, 21	√	5.61462	x		x			
6 + 18	√	4.37004	x		x			
8 + 14	√	0.22699	x		x			
8 + 22	√	4.22039	√	2.41186				
14 + 22	√	3.19588	x		x			
8, 14, 22	√	5.4320	x		x			
10 + 24	√	1.71776	√	0.14663	x			
12 + 19	x		x		x			
12 + 23	√	0.10028	√	2.24173	√	1.47903	-4.680	2.941
19 + 23	x		x		x			

total lengths of fish in the Otago samples for May, November, and February were 57.09 cm, 46.68 cm, and 10.73 cm respectively. Similarly, for the February, May, and September C.B.C.C. samples, the means were 61.10 cm, 19.40 cm, and 52.16 cm. There was also considerable variation in the composition of samples from the other areas.

That all these samples came from different areas would also have contributed to variations in b.

Because of the inconsistencies in the samples from these other areas, it is very difficult to compare their length-weight relationships, one with another. It is also difficult to decide which relationship should hold for any particular area.

Nevertheless, analysis of covariance was used to compare the regression lines in Figure 32. Where samples coincided by month, the regressions for these other areas were also compared with those of the Canterbury samples. Results of testing are presented in Table 26.

Of the 29 comparisons made, variances were homogeneous in 23. Of these, a common slope could describe 10. However, there were only 2 comparisons which could also be described by a common intercept. These findings bear out the above views on the difficulty of comparing these regressions.

The samples which were most alike were those for C.B.C.C., February and September 1972, and the Canterbury and C.B.C.C. September 1972 samples.

That these combinations indicated similarity is surprising. Although the C.B.C.C. samples were of similar composition (Mean red cod lengths of 61.1 cm and 52.2 cm), their regression equations were considerably different (See Fig. 32). As for the second combination, the composition of each of the samples was quite different (Mean red cod lengths of 31.3 cm, Canterbury sample, 52.2 cm, C.B.C.C. sample).

Clearly, there is a need for further samples from all areas, under more rigid conditions of sampling, before any meaningful descriptions can be made of their length-weight relationships.

4.4 Summary

1 The use of length frequency analyses in the study of age and growth in fishes is discussed. Although the samples taken in this study were of limited representativeness, analyses were

nevertheless carried out.

2 Some 8 131 red cod were measured from the following areas: Canterbury (4 384), Otago (403), Foveaux Strait (142), W.C.S.I. (227), W.C.N.I. (2 019), C.B.C.C. (905), and East Cape (51).

3 The Canterbury samples, which were obtained during October 1971 - October 1972, showed 6 relatively discreet modes in their distributions. These indicated the following age classes:

0+ - May and August, 1972

1+ - November 1971 and October 1972

2+ - October 1971 and June 1972

which were isolated using probability paper. Further modes were similarly isolated in the samples from the other areas.

4 For the Canterbury samples, information on age classes allowed tentative estimates of growth. Canterbury red cod grow about 20 cm in length in both their first and second years of life.

5 The derivation and uses of the length-weight relationship are described, and this relationship calculated for all monthly samples from Canterbury (October, 1971 - October, 1972), Otago (May and November, 1971, February, 1972), Foveaux Strait (November 1971), W.C.S.I. (March, 1972), W.C.N.I. (September, 1971, October 1973), C.B.C.C. (February, May and September 1972), and East Cape (July, 1973).

6 For the Canterbury samples isometric growth was indicated, as, in only one sample (January, 1972) did b differ significantly from 3. However, in 8 out of 11 samples from other areas, allometric growth is indicated. It is suggested that the indications of allometry in these samples is due to variations in the composition of the samples and sample size.

7 All regression lines were compared using analysis of covariance. Of the 52 comparisons made, variances were homogeneous in 40, a common slope could be fitted to 21, and a common intercept to 7.

8 Suggestions are made regarding which length-weight relationships should apply in the Canterbury area. However, it is also suggested that further observations are needed before this relationship can be defined for the other areas studied.

SECTION 5

FOOD AND FEEDING OF THE RED COD

5.1 Introduction

"The importance of the study of the food of fishes with its bearings on the different aspects of their biology... is well known..." (Venkataraman, 1960). There is an extensive, if scattered, literature on food studies in fishes which supports this statement. A major objective in such studies is to determine the nature of the diet of the species concerned. This usually includes a quantitative and qualitative determination of the kinds and amounts of food consumed in relation to such factors as the influence of habitat, season, water temperature, preferences, fish size, prey size, prey availability, and diel feeding rhythms. Methods vary considerably, as do particular points of emphasis. Much of this variation results from the differences between the species being studied. As Thompson (1959a) stated, "The problems of stomach contents analysis and methods of presentation are difficult ones and should be approached anew with each species and purpose of study."

Little has been written about the food and feeding of the red cod *Pseudophycis bacchus*. Brief synopses have been written by Thomson (1892, 1913), Waite (1911), Thomson and Anderton (1921), Phillipps (1926, 1927a), Parrott (1957), Moreland (1963), Heath and Moreland (1967), Doogue and Moreland (1969), Russell (1971a), and Webb (1973).

The only substantial work was reported by Graham (1939a) and later alluded to in Graham (1953, 1956). Although he examined over a thousand red cod stomachs, his findings are of limited value because he only listed what was present: no quantitative data were collected. His findings however were interesting because they confirmed the popular opinion that this species is an "Indiscriminate devourer(s) of animals and plants..." (Graham, 1939a). He found that red cod ate 28 species of fish, 8 species of molluscs, 12 species of "crabs" (brachyurans and porcellanids), 10 species of other crustaceans such as amphipods and isopods, 5 species of annelids, 1 species of echinoderm, and various miscellaneous items including hydrozoans, ascidians, and flotsam.

The aim of my study was to carry out a qualitative and quantitative analysis of the food and feeding of the red cod in New Zealand waters.

5.2 Materials and Methods

5.2 a Sampling

During the period May 1971 - October 1973, samples of red cod were obtained from seven areas around New Zealand (See Section 1 for details of areas, which are indicated in Fig. 4 of that Section). As soon as possible after capture, alimentary tracts were dissected out of the fish and placed in formalin to halt digestion. These were then stored for later analysis at the laboratory. At the conclusion of the fieldwork, stomach analyses were carried out in a more-or-less continuous operation so as to promote consistency in the subjective aspects of stomach analyses, and minimize errors. For each fish, length, weight and sex were noted.

5.2 b Samples by area

5.2 b i Canterbury samples

Monthly samples were collected from this area between October 1971 - October 1972. Details of sample size by sex are presented in Table 27.

Table 27: Monthly sample sizes of red cod captured in the Canterbury area for food and feeding studies (F = female, M = male).

	F	M	Totals
October 1971	91	119	210
November 1971	65	37	102
December 1971	18	26	44
January 1972	50	38	88
February 1972	49	107	156
March 1972	94	154	248
April 1972	26	81	107
May 1972	69	106	175
June 1972	153	177	330
July 1972	86	124	210
August 1972	55	88	143
September 1972	86	33	119
October 1972	183	179	362
Totals	1 025	1 269	2 294

5.2 b ii Otago samples

Samples were collected for the months May 1971, November 1971 and February 1972 from this area. Details of sample size by sex are presented in Table 28.

Table 28: Sample sizes of red cod from Otago.

	F	M	Totals
May 1971	21	18	39
November 1971	98	30	128
February 1972	34	57	91
Totals	153	105	258

5.2 b iii Foveaux Strait sample

A sample was collected in November 1971. Details of sample size by sex are presented in Table 29.

Table 29: Foveaux Strait red cod sample.

	F	M	Totals
November 1971	104	18	122

5.2 b iv West Coast South Island (W.C.S.I.) sample

A sample was collected from this area in March 1972. Details of sample size by sex are presented in Table 30.

Table 30: W.C.S.I. red cod sample.

	F	M	Totals
March 1972	76	134	210

5.2 b v West Coast North Island (W.C.N.I.) samples

Samples were collected from this area in September and November 1971, and October 1973. Details of sample size by sex are presented in Table 31.

Table 31: W.C.N.I. red cod samples.

	F	M	Totals
September 1971	45	50	95
November 1971	32	16	48
October 1973	44	16	60
Totals	121	82	203

5.2 b vi Cloudy Bay - Cape Campbell (C.B.C.C.) samples

Samples were collected from this area in February, May and September 1972. Details of sample size by sex are presented in Table 32.

Table 32: C.B.C.C. red cod samples.

	F	M	Totals
February 1972	13	6	19
May 1972	57	108	165
September 1972	27	8	35
Totals	97	122	219

5.2 b vii East Cape sample

In July 1973, a sample of red cod was taken from this area. Sample size by sex is presented in Table 33.

Table 33: East Cape red cod sample.

	F	M	Totals
July 1973	21	30	51

5.2 c The anatomy of the alimentary tract and its functioning

The alimentary tract of a fish can be conveniently regarded as comprising two main regions (Banki, 1936, cited by Barrington, 1957). These are the "Kopfdarm", or buccal cavity and pharynx, and the "Rumpfdarm", or foregut (oesophagus and stomach), midgut (intestine), and hindgut (rectum).

In the red cod, a large buccal cavity leads by way of a short pharynx-oesophagus into a large muscular stomach which occupies a large part of the abdominal cavity. The dorsal part of the stomach gives rise to the intestine which passes backwards, then forwards, and finally backwards to the rectum and anus. Pyloric caeca are given off by the intestine near its junction with the stomach (See Beattie, 1891, pl. XII).

The stomach is the main repository for food, which arrives here little changed from its original form, and undergoes almost complete digestion. Because of its major role in feeding and digestion, only the stomach was analysed in this study. This has many precedents. Hynes (1950) stated that "Most workers studying the food of... fish have based their conclusions on a study of the contents of the stomach." He attributes this to digestion being less advanced in the stomach, thus allowing reasonably satisfactory identification of contents.

5.2 d Methods of assessment of stomach contents

5.2 d i Historical

Hynes (1950) presented a review of the methods used in studies of the food of fishes. He noted that although some workers have merely listed the food organisms found in each fish, most have analysed their data by one or more of the methods he listed. Briefly these were:

(1) The occurrence method in which the number of fish in which each food item occurs is listed as a percentage of the total number of fish examined;

(2) The number method in which individual food items are counted and counts usually expressed as percentages of the total number of organisms found in all fish examined.

(3) The dominance method in which the dominant food item is recorded for each fish and relative occurrences of each dominant item calculated as percentages;

(4) The volume and weight methods in which the volume or weight of each food item or of total food of each fish is related to the weight of the fish;

(5) The fullness method in which an arbitrary scale of stomach fullness is employed; and

(6) The points method in which the volume of each food item is estimated by taking size and abundance into account and points are allotted according to volume.

After considering all these methods, Hynes used a modified points method, despite its limitations, such as its subjectivity, and inflexibility in relation to making comparisons with counts of organisms in the habitat. However he pointed out that subjectivity is a fault in many of the other methods, and elaborated on the merits of the points method (See Hynes, 1950, p. 37).

Thompson (1959a) also discussed methods of assessment of stomach contents and adopted Hynes technique with slight modification.

In this study, the main method used was Thompson's with some modifications. Information was also gained from using methods 1, 4, and 5 as outlined above.

5.2 d ii Dissection, and the assessment of the stomach contents of red cod

The stomachs were dissected out of the alimentary tracts of red cod, blotted, and weighed to the nearest 0.01 g. For any particular sample, further analysis was as follows:

(1) Before opening each stomach, stomach points were allocated according to degree of fullness, on a continuous scale from 0, representing an empty stomach to 20 for a full one. The allocation of points prior to identification and evaluation of the food items prevented the possibility that large, relatively undigested items, might be over-estimated in terms of their volumetric importance.

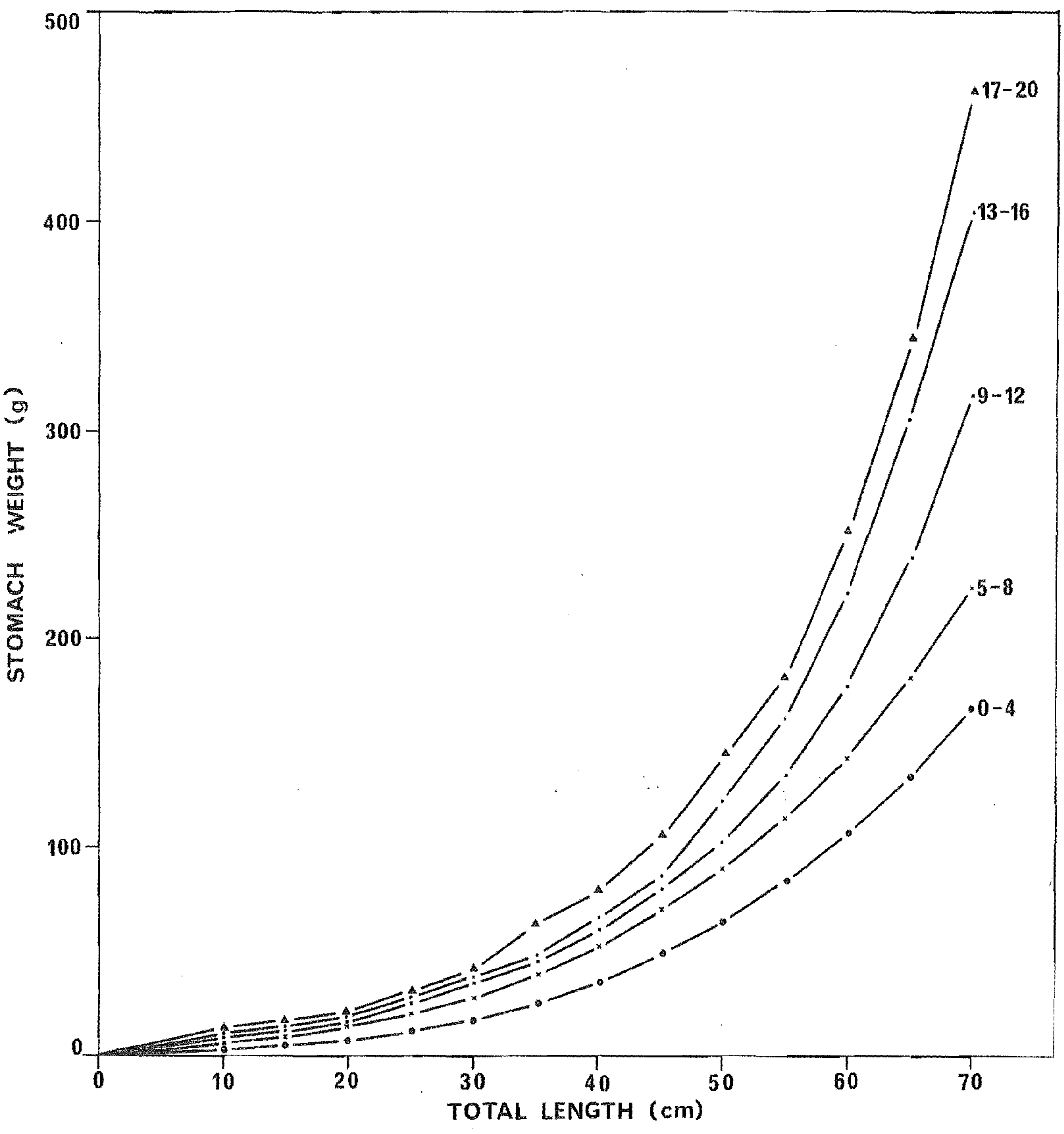
(2) Each stomach was then opened and the points distributed among the food items present. Items then became represented according to their relative volumes in the whole of the stomach contents.

Most food items were macroscopic and readily identifiable by eye. Occasionally, a binocular dissecting microscope was used to key out food species and identify small food items.

FIGURE 33

The stomach weight-fish length relationships for red cod containing varying amounts of food in their stomachs in the 3-month category October - December.

0-4	Empty to 1/4 full
5-8	Just over 1/4 to just over 1/3 full
9-12	About 1/2 full
13-16	2/3 to 3/4 full
17-20	Almost full to completely full



500
400
300
200
100
0
STOMACH WEIGHT (g)
0
10
20
30
40
50
60
70
TOTAL LENGTH (cm)
17-20
13-16
9-12
5-8
0-4

(3) The number of fish in the sample was multiplied by 20. This gave the maximum number of points which could be gained by the sample.

(4) Points gained by each food item were then converted into volume percentages of the maximum points possible.

(5) The empty volume was estimated by subtracting the points gained by all food items from the maximum points possible.

(6) Finally, the points gained by the food items were converted to volume percentages of the total points gained by food items in the sample.

For samples collected in the Canterbury area, much of the subjectivity in allocating points to a stomach was removed by establishing stomach weight-fish length relationships.

The sample year was divided into the three-month categories January - March, April - June, July - September, and October - December. From each category, a representative sample of 50 fish was taken and analysed by the procedure outlined above. Fish were then separated out according to whether their stomachs gained 0-4, 5-8, 9-12, 13-16, or 17-20 points. Stomach weights were then plotted against fish length for each of the above points categories. This produced a series of curved lines of increasing slope, from that for the 0-4 points category, to that for the 17-20 category.

In subsequent points allocations, information on stomach weight and fish length rapidly indicated the points category to which particular stomachs belonged. Finer judgements were then made regarding the number of points a stomach should be allocated within that category.

The lines for the three-month category October - December are presented in Figure 33 as an illustration of the technique.

5.2 e Further analyses

The following analyses were carred out on all samples:

(1) The calculation of the mean stomach weight per month;

(2) The calculation of monthly stomach fullness indices i.e. mean stomach weight as a percentage of mean fish gutted weight;

(3) The calculation of fish length-stomach weight regressions for each month.

For the Canterbury samples, the relationships between the size of the prey species *Cheilodactylus macropterus* (tarakihi) and *Helicolenus papillosus* (sea perch), and the size of the predator, the red cod, were established.

5.3 Results and Discussion

5.3 a List of food items

These are listed in Table 34. The order is that in which items were coded for analysis.

Table 34: List of food items found in the diet of red cod caught in the New Zealand region, intermittently, during the period May 1971 - October 1973.

Code	Category of food item	Specific name	Common name
1			remains
2			fish remains
3			crustacean remains
4			molluscan remains
5			annelid remains
6	UNIDENTIFIED		crabs
7			amphipods
8			shrimps
9			isopods
10			polychaetes
11			gastropods
12			debris
	FISHES - ELASMOBRANCHII		
13	F - SQUALIDAE	*Squalus acanthias* Linnaeus, 1758	Spotted spiny dogfish
14	F - EMISSOLIDAE	*Mustelus antarcticus* Günther, 1870	Spotted smooth-hound
15	F - CALLORHYNCHIDAE	*Callorhynchus milii* Bory de St Vincent, 1823	Elephant fish
	FISHES - TELEOSTEI		
16	F - CLUPEIDAE	*Sardinops neopilchardus* (Steindachner, 1879)	Pilchard
17	F - "	*Sprattus antipodum* (Hector, 1872)	Sprat

Table 34: Continued

Code	Category of food item	Specific name	Common name
18	F - ARGENTINIDAE	*Argentina elongata* Hutton, 1879	Silverside
19	F - RETROPINNIDAE	*Retropinna retropinna* (Richardson, 1848)	Smelt
20	F - GALAXIIDAE	*Galaxias maculatus* (Jenyns, 1842)	Whitebait
21	F - MYCTOPHIDAE	*Myctophus* sp.	Lanternfish
22	F - LEPTOCEPHALIDAE	*Conger verreauxi* Kaup, 1856	Conger eel
23	F - ECHELIDAE	*Muraenichthys breviceps* Griffin, 1921	Worm eel
24	F - MACRORHAMPHOSIDAE	*Macrorhamphosus elevatus* Waite, 1899	Snipefish
25	F - "	*Centriscops humerosus* (Richardson, 1846)	Banded bellowsfish
26	F - "	*Notopogon lilliei* Regan, 1914	Crested bellowsfish
27	F - SYNGNATHIDAE	*Novacampus norae* (Waite, 1910)	Long-snouted pipefish
28	F - "	*Hippocampus abdominalis* Lesson, 1827	Seahorse
29	F - MACROURIDAE	*Coelorhynchus australis* (Richardson, 1839)	Javelin fish
30	F - MERLUCCIDAE	*Macruronus novaezelandiae* (Hector, 1871)	Hoki, whiptail
31	F - "	*Merluccius gayi* (Guichenot, 1847)	English hake, whiting
32	F - MORIDAE	*Pseudophycis bacchus* (Bloch and Schneider, 1801)	Red cod
33	F - "	*Auchenoceros punctatus* (Hutton, 1873)	Ahuru
34	F - TRACHICHTHYIDAE	*Paratrachichthys trailli* (Hutton, 1875)	Roughy
35	F - ZEIDAE	*Zeus faber* Linnaeus, 1758	John dory
36	F - "	*Zenopsus nebulosus* (Timminck and Schelegel, 1845)	Mirror dory

Table 34: Continued

Code	Category of food item	Specific name	Common name
37	F - ZEIDAE	*Cyttus australis* (Richardson, 1842)	Boarfish
38	F - "	*Cyttus novaezelandiae* (Arthur, 1885)	Silver dory
39	F - BOTHIDAE	*Arnoglossus scapha* (Bloch and Schneider, 1801)	Witch, megrim
40	F - PLEURONECTIDAE	*Rhombosolea plebeia* (Richardson, 1843)	Sand flounder,
41	F - "	*Rhombosolea leporina* Günther, 1873	Yellowbelly flounder
42	F - "	*Pelotretis flavilatus* Waite, 1910	Lemon sole
43	F - "	*Peltorhamphus novaezeelandiae* (Günther, 1862)	Common sole
44	F - CENTROLOPHIDAE	*Seriolella porosa* Guichenot, 1849	Silver warehou
45	F - "	*Seriolella brama* (Günther, 1860)	Warehou
46	F - "	*Seriolella maculata* (Forster, 1794)	Silverfish, bastard warehou
47	F - SERRANIDAE	*Ellerkeldia semicincta* (Cuvier and Valenciennes, 1833)	Half-banded sea perch
48	F - LEPIDOPIDAE	*Lepidopus caudatus* (Euphrasen, 1788)	Frostfish
49	F - SPARIDAE	*Chrysophrys auratus* (Bloch and Schneider, 1801)	Snapper
50	F - SCORPAENIDAE	*Scorpis aequipinnis* Richardson, 1848	Blue maomao
51	F - "	*Helicolenus papillosus* (Bloch and Schneider, 1801)	Seaperch
52	F - CHEILODACTYLIDAE	*Cheilodactylus macropterus* (Bloch and Schneider, 1801)	Tarakihi
53	F - LEPTOSCOPIDAE	*Crapatalus novaezelandiae* Günther 1861	Sandfish

Table 34: Continued

Code	Category of food item	Specific name	Common name
54	F - URANOSCOPIDAE	*Genyagnus monopterygius* (Bloch and Schneider, 1801)	Spotted monkfish
55	F - "	*Kathetostoma giganteum* Haast, 1873	Stargazer, flathead
56	F - NOTOTHENIIDAE	*Notothenia microlepidota* Hutton, 1876	Black cod
57	F - GEMPYLIDAE	*Thyrsites atun* (Euphrasen, 1791)	Barracouta
58	F - "	*Rexea solandri* (Cuvier and Valenciennes, 1832)	Southern kingfish
59	F - PERCOPHIDIDAE	*Hemerocoetes monopterygius* (Bloch and Schneider 1801)	Opalfish
60	F - "	*Hemerocoetes waitei* Regan, 1914	Bluebonnet
61	F - TRIPTERYGIIDAE	*Forsterygion varium* (Bloch and Schneider, 1801)	Cockabully
62	F - "	*Helcogramma medium* (Günther, 1861)	Twister
63	F - OPHIDIIDAE	*Genypterus blacodes* (Bloch and Schneider, 1801)	Ling
64	F - CONGIOPODIDAE	*Congiopodus leucopaecilus* (Richardson, 1846)	Pigfish
65	F - OPLICHTHYIDAE	*Hoplichthys haswelli* McCulloch, 1907	Deep-sea flathead
66	F - TRIGLIDAE	*Chelidonichthys kumu* (Lesson and Garnot, 1829)	Red gurnard
67	F - BALISTIDAE	*Cantherines scaber* (Bloch and Schneider, 1801)	Leatherjacket
	NATANT DECAPOD CRUSTACEA		
68a	F - PALAEMONIDAE	*Palaemon affinis* H. Milne-Edwards, 1837	
68b	F - "	*Periclimenes (Harpilius) yaldwyni* Holthuis, 1959	
69	F - CRANGONIDAE	*Pontophilus australis* (Thomson, 1879)	

Table 34: Continued

Code	Category of food item	Specific name	Common name
70	F - CRANGONIDAE	*Pontophilus pilosoides* Stephensen, 1927	
71	F - ALPHEIDAE	*Alpheus socialis* Heller, 1865	
72	F - PANDALIDAE	*Notopandalus magnoculus* (Bate, 1888)	
73	F - HIPPOLYTIDAE	*Nauticaris marionis* Bate, 1888	
74	F - SERGESTIDAE	*Sergestes potens* Burkenroad, 1940	
	REPTANT DECAPOD CRUSTACEA		
75	F - CALLIANASSIDAE	*Callianassa filholi* A. Milne-Edwards, 1878	Ghost shrimp
76	F - PALINURIDAE	*Jasus edwardsii* (Hutton 1875)	Crayfish, rock lobster
77	F - GALATHEIDAE	*Munida gregaria* (Fabricius, 1793)	Whalefeed
78	F - PAGURIDAE	*Pagurus* sp.	Hermit crab
79	F - LITHODIDAE	*Lithodes murrayi* Henderson, 1888	Southern stone crab
80	F - HOMOLIDAE	*Lattreillopsis petterdi* Grant, 1905	Antlered crab
81	F - LEUCOSIIDAE	*Ebalia laevis* (Bell, 1855)	Nut crab
82	F - RANINIDAE	*Lyreidus tridentatus* De Haan, 1841	Harp crab
83	F - MAJIDAE	*Naxia huttoni* (A. Milne-Edwards, 1876)	Hutton's masking crab
84	F - "	*Notomithrax peronii* (H. Milne-Edwards, 1834)	Peron's seaweed
85	F - "	*Notomithrax ursus* (Herbst, 1788)	Hairy seaweed crab
86	F - "	*Notomithrax minor* (Filhol, 1885)	Lesser seaweed crab
87	F - "	*Leptomithrax longimanus* Miers, 1876	Long-handed masking crab
88	F - "	*Leptomithrax australis* (Jacquinot, 1853)	Giant masking crab
89	F - "	*Leptomithrax longipes* (Thomson, 1902)	Long-legged masking crab

Table 34: Continued

Code	Category of food item	Specific name	Common name
90	F - MAJIDAE	*Leptomithrax richardsoni* Dell, 1960	Richardson's masking crab
91	F - "	*Jacquinotia edwardsii* (Jacquinot, 1853)	New Zealand giant crab
92	F - HYMENOSOMATIDAE	*Halicarcinus innominatus* Richardson, 1949	Rounded sea spider
93	F - "	*Elamena producta* Kirk, 1878	Paua sea spider
94	F - ATELECYCLIDAE	*Trichopeltarion fantasticum* Richardson and Dell, 1964	Frilled crab
95	F - PORTUNIDAE	*Nectocarcinus antarcticus* (Jacquinot, 1853)	Red swimming crab
96	F - "	*Ovalipes punctatus* (de Haan, 1835)	Common swimming crab
97	F - GONEPLACIDAE	*Ommatocarcinus macgillivrayi* (White, 1852)	Policeman crab
98	F - PINNOTHERIDAE	*Pinnotheres novaezelandiae* Filhol, 1886	Pea crab
99	F - GRAPSIDAE	*Hemigrapsus crenulatus* (H. Milne-Edwards, 1837)	Hairy-handed crab
100	F - "	*Helice crassa* Dana, 1851	Tunneling mud crab
101	F - "	*Cyclograpsus lavauxi* H. Milne-Edwards, 1853	Smooth shore crab
102	F - "	*Plagusia chabrus* (Linnaeus, 1764)	Red rock crab
103	F - OCYPODIDAE	*Macrophthalmus (Hemiplax) hirtipes* (Jacquinot, 1853)	Stalk-eyed mud crab
	O - AMPHIPODA		
104	F - TALITRIDAE	*Hyale rubra* (G.M. Thomson, 1879)	
105	F - "	*Hyale media* (Dana, 1852)	
106	F - "	*Allorchestes novizealandiae* Dana, 1852	

Table 34: Continued

Code	Category of food item	Specific name	Common name
107	F - AMPELISCIDAE	*Ampelisca chiltoni* Stebbing, 1888	
	O - ISOPODA		
108	F - AEGIDAE	*Rocinela garricki* Hurley, 1957	Fish louse
109	F - SPHAEROMIDAE	*Isocladus armatus* (H. Milne-Edwards, 1840)	Pill bug isopod
110	F - EURYDICIDAE	*Cirolana arcuata* Hale, 1925	Fish louse
111	F - CYMOTHOIDAE	*Codonophilus lineatus* (Miers, 1876)	Fish louse
	O - STOMATOPODA		
112	F -	*Squilla armata* Edwards, 1837	Mantis shrimps
113	F -	*Heterosquilla tricarinata* (Claus, 1871)	
114	O - EUPHAUSIACEA	*Nyctiphanes australis* G.O. Sars, 1883	
115	O - MYSIDACEA	*Australomysis* sp.	Opposum shrimp
	MOLLUSCA - GASTROPODA		
116	F - UMBONIIDAE	*Zethalia zelandicum* (A. Adams, 1854)	Wheel shell
117	F - NEPTUNIDAE	*Austrofusus glans* (Roeding, 1798)	Knobbed whelk
118	F - FISSURELLIDAE	*Scutus breviculus* (Blainville, 1817)	Shield shell
119	F - COMINELLIDAE	*Cominella quoyana* A. Adams, 1854	Cominella shell
120	F - TURRITELLIDAE	*Maoricolpus roseus roseus* (Quoy and Gaimard, 1834)	Turret shell
121	F - TROCHIDAE	*Maurea punctulata punctulata* (Martyn, 1784)	Maurea top shell
	MOLLUSCA - PELECYPODA		
122	F - PECTINIDAE	*Pecten novaezelandiae novaezelandiae* Reeve, 1852	Queen scallop
123	F - AMPHIDESMATIDAE	*Amphidesma australe australe* (Gmelin, 1790)	Pipi

Table 34: Continued

Code	Category of food item	Specific name	Common name
124	F - AMPHIDESMATIDAE	*Amphidesma forsterianum* Finlay, 1927	Southern tuatua
125	F - MACTRIDAE	*Cyclomactra ovata* (Gray, 1843)	Oval trough shell
126	F - CARDITIDAE	*Venericardia purpurata* (Deshayes, 1854)	Purple cockle
127	F - VENERIDAE	*Chione stutchburyi* (Gray, 1828)	Common cockle
	MOLLUSCA - CEPHALOPODA		
128	F - OCTOPODIDAE	*Octopus maorum* Hutton, 1880	Octopus
	ANNELIDA - POLYCHAETA		
129	F - NEREIDAE	*Platynereis australis* (Schmarda, 1861)	
	ECHINODERMATA		
130		*Echinocardium australe*	Heart urchin
	UROCHORDATA		
131	F - CIONIDAE	*Ciona intestinalis*	Sea squirt
132	F - PYURIDAE	*Pyura pachydermatina* (Herdman)	Sea tulip
133	F - SALPIDAE	*Pyrosoma atlanticum*	Salp

Of the 134 separate items of food, 12 were in the unidentified category, 3 were elasmobranch fishes, 52 teleost fishes, 8 natant decapod crustaceans, 29 reptant decapod crustaceans, 4 amphipods, 4 isopods, 2 stomatopods, 1 euphausid, 1 mysid, 13 molluscs, 1 polychaete, 1 echinoderm, and 3 urochordates.

This highly varied dietary list can be further expanded by referring to the findings of other workers. For example, Graham (1939a) found 11 species of fish, 10 of crustaceans, 6 of molluscs, 5 of annelids, 1 of echinoderm, and miscellaneous urochordates and flotsam which do not appear in the above list. Yet other food items were reported by Thomson (1892, 1913), Waite (1911), Phillipps (1926, 1927a), Russell (1971a), and Webb (1973).

5.3 b Feeding analyses by species by month by area

The following statistics were calculated for the monthly samples taken from all areas:

(1) Percentage of food by volume - where each food item became represented as a percentage of the total quantity of food present;

(2) Percentage of available stomach volume - where each food item became represented as a percentage of the available stomach volume;

(3) Percent occurrence - where each food item became represented as a percentage of the number of times it occurred (this is essentially the numbers method as outlined by Hynes (1950, p. 36) and criticised by Thompson (1959a, p. 46)).

In addition, two further statistics were calculated for the Canterbury samples:

(1) Average number of points per occurrence - where each food item present became represented as an average of all the times it occurred in the monthly samples, divided by the total points gained for the same monthly samples;

(2) A feeding diversity index (FDI). There were 118 food items in Canterbury samples. During any month, considerably fewer than this were present. Monthly totals were calculated as percentages of the total number of items possible in each sample, i.e. of 118, thus generating FDIs.

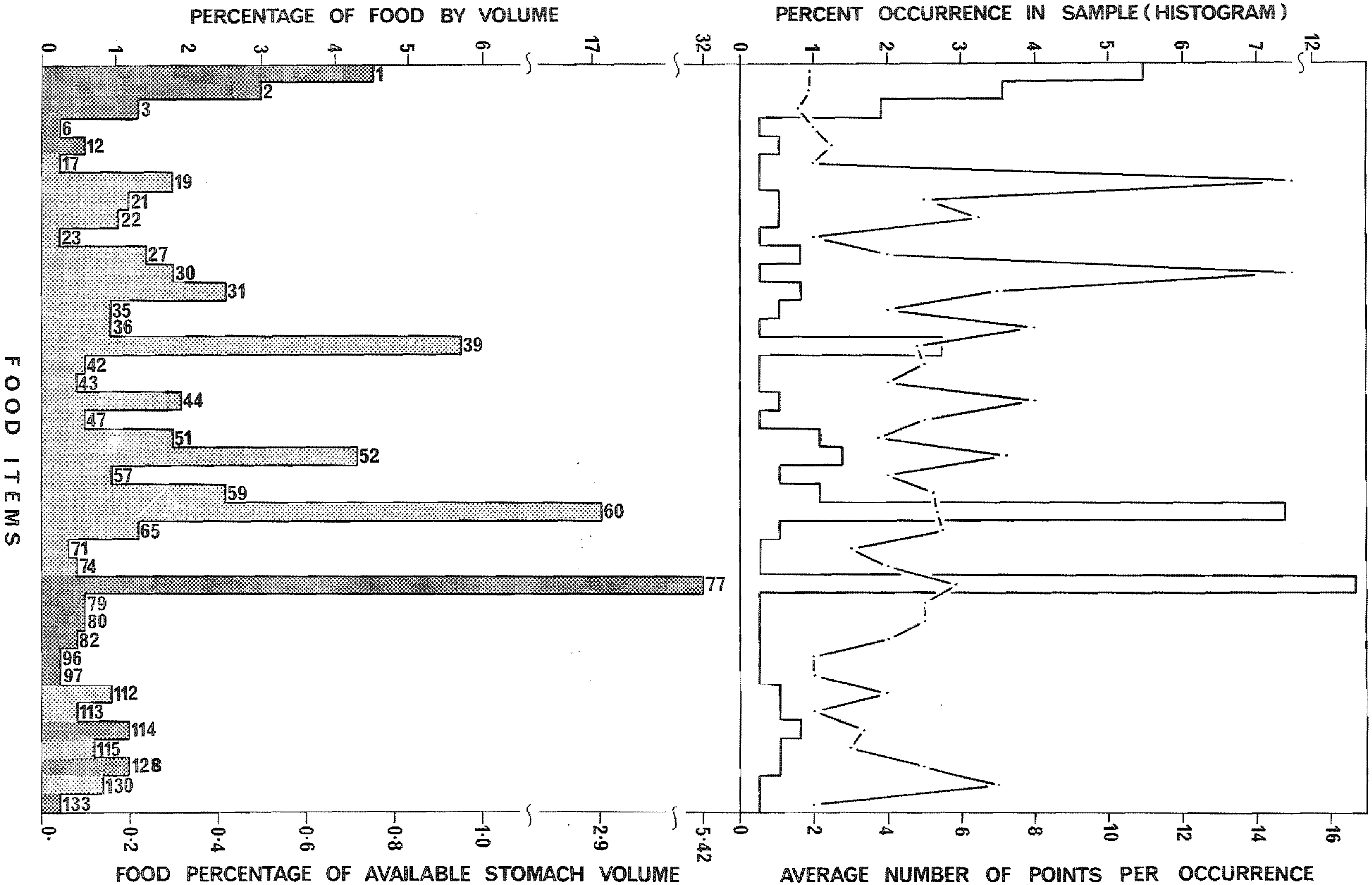
Although the above analyses were in terms of individual food items, this information was combined when necessary to produce grand percentages, representative of the major food categories in Table 34. The major food categories were (1) Unidentified, (2) Fishes, (3) Natant decapod Crustacea, (4) Reptant decapod Crustacea, (5) Amphipoda, (6) Isopoda, (7) Stomatopoda, (8) Euphausiacea, (9) Mysidacea, (10) Mollusca-Gastropoda, (11) Mollusca-Pelecypoda, (12) Mollusca-Cephalopoda, (13) Annelida-Polychaeta, (14) Echinodermata, and (15) Urochordata. In Figures 34-44, these categories, where present, are indicated by alternate light and dark shadings.

No differences were apparent in food and feeding for male and female cod. Therefore all results were amalgamated.

FIGURE 34

Canterbury area feeding analyses by individual food items for October 1971. The key to food item code numbers is presented in Table 34.

n = 210 FDI = 33.90%


PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
0 1 2 3 4 5 6 17 32
0 1 2 3 4 5 6 7 12
0· 0·2 0·4 0·6 0·8 1·0 2·9 5·42
0 2 4 6 8 10 12 14 16
1 2 3 6 12 17 19 21 22 23 27 30 31 35 36 39 42 43 44 47 51 52 57 59 60 65 71 74 77 79 80 82 96 97 112 113 114 115 128 130 133

5.3 b i Canterbury samples by month (See also Tables 27 and 34)

5.3 b i (1) October 1971, results and discussion

Results of feeding analyses are presented in Figure 34.

Percentage of food by volume

Of the 40 food items present in this sample, 4 contributed almost two-thirds of the volume of food. These were *Munida* (46.90%), red swimming crab (10.44%), common swimming crab (4.59%), and seaperch (4.01%). Two-thirds of the remaining food species had individual percentages of less than 1%.

It is interesting that the dominant food species were pelagic or in pelagic phases of their life cycles (See Thomson and Thomson, 1923; Young, 1925; Williams, 1973a). While being basically adapted to feeding on bottom-dwelling organisms (See Graham, 1953, p. 170), the red cod is obviously sufficiently adaptable to enable it to feed in the mid to surface waters on pelagic species.

It would seem that other bottom-dwelling fishes might also forego their traditional feeding niches in favour of pursuing pelagic species, especially *Munida*. The author received a report (Mr L. Luxton, Lyttelton fisherman, pers. comm.) of red gurnard *Chelidonichthys kumu,* a bottom-dwelling fish, feeding at the surface on *Munida*.

In terms of food categories for this monthly sample, reptant decapod crustaceans comprised the bulk of the diet of red cod (65.71%), followed by fishes (15.48%), unidentified (9.40%), natant decapods (4.36%), molluscs (2.17%), amphipods (1.49%), stomatopoda (1.38%), and isopods (0.92%).

Percentage of available stomach volume

The actual percentage volumes of food species present in relation to the available stomach volume were approximately 20% less than the values presented in the preceding discussion on food species percentages relative to the total volume of food. The same comparisons apply. A low feeding rate was demonstrated in this sample, with only 20.76% of the available stomach volume being occupied by food.

Percent occurrence

Predictably, the histogram for percent occurrence followed the general form of that for percentage of food by volume. It is to be expected that high volume occurrences would correspond with high numbers occurrences. However the range in percentages between the less important and the more important food species was considerably less by the numbers method. Thompson's (1959a) criticism of this method of evaluating food items is borne out in part. Undue emphasis has been placed on the small food items with the result that an inflated estimate of their worth as food in relation to the dominant food items is gained.

Average number of points per occurrence

There was no obvious pattern of variation in this parameter. Several species which occurred very infrequently, comprised a large part of the stomach contents of individual fish. For example, octopus (code number 128) occurred only once in the October 1971 sample. However it occupied four-fifths of the total available stomach volume of the fish in which it was found. Another example is provided by hoki (code number 30). In both cases, the prey species were large in relation to the size of the red cod.

The occasional evidence of this type of feeding is indicative of the opportunistic aspect of red cod feeding and provides evidence of its predaceous abilities.

The more frequently occurring species had low average points (*Munida* - 6.49, red swimming crab - 3.37, common swimming crab - 3.64, seaperch - 4.37) per occurrence.

Feeding diversity index (FDI)

There were 40 food items present giving a FDI of 33.90%.

Comment

Discussion on all aspects of feeding analyses for all months as presented above would be unnecessarily repetitive as the same data are discussed within any one month. In addition, direct relationships exist between percentage of food by volume, percentage of available stomach volume, and percent occurrence. These relationships are indicated above, and in the figures. For subsequent months therefore, only the first of these three aspects will be discussed. Also discussed will be the feeding diversity index.

Perusal of the aspect, average number of points per occurrence, for all months showed that this varied as a function of the size of

FIGURE 35

Canterbury area feeding analyses by individual food items for November 1971. The key to food item code numbers is presented in Table 34.

n = 102 FDI = 30.51%

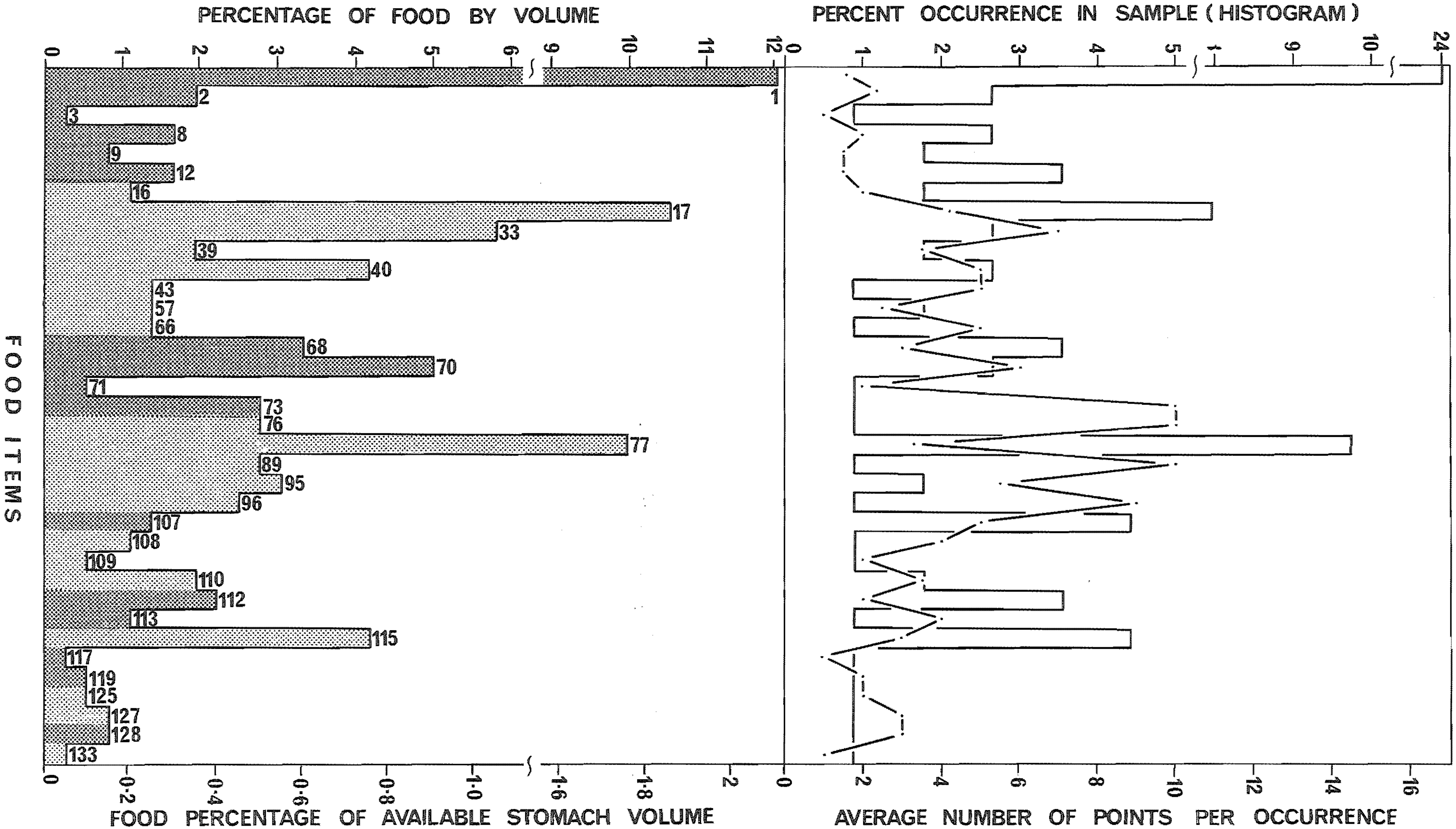

PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
1
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FIGURE 36a

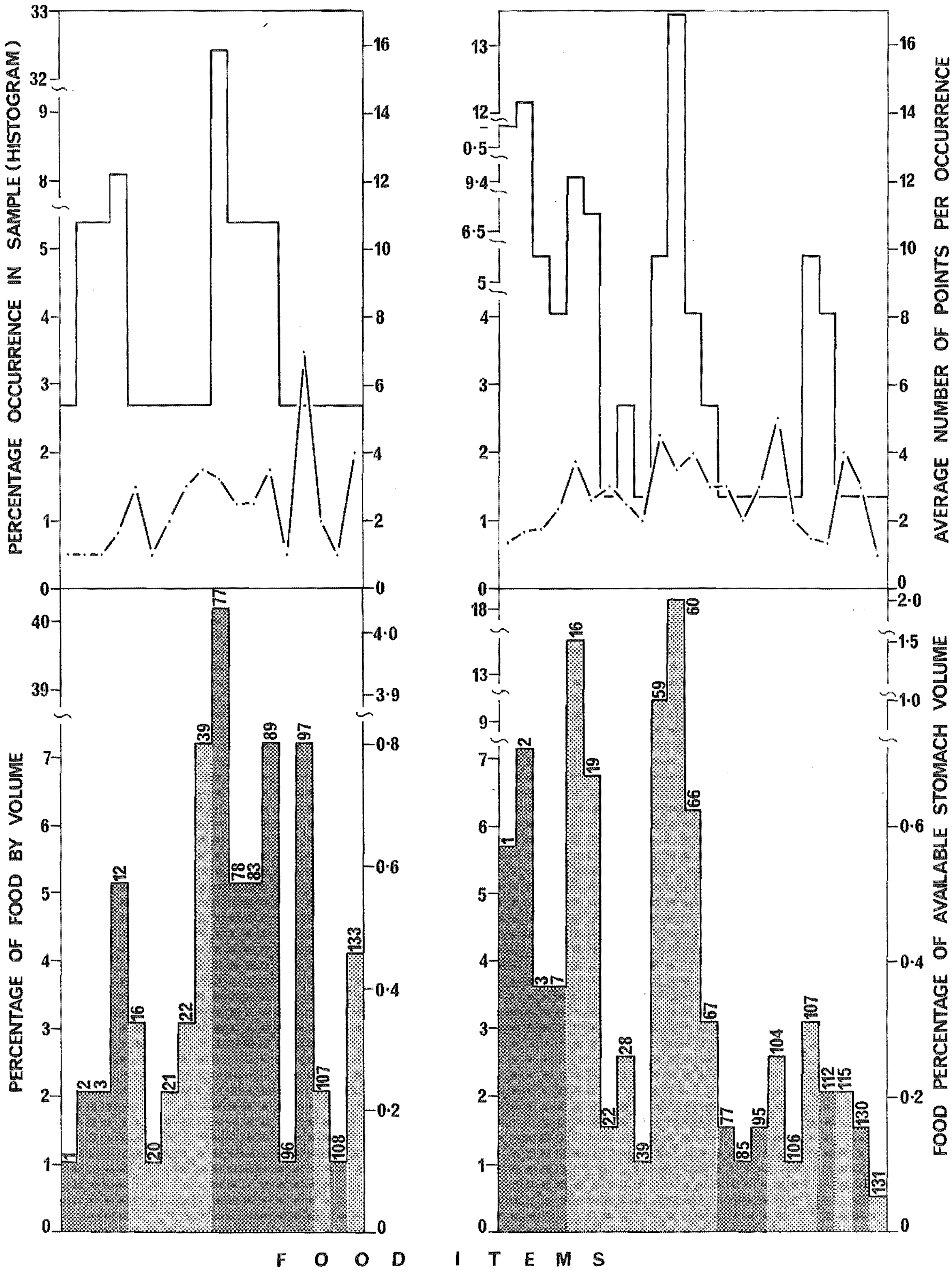
Canterbury area feeding analyses by individual food items for December, 1971. The key to food item code numbers is presented in Table 34.

n = 44 FDI = 15.25%

FIGURE 36b

Canterbury area feeding analyses by individual food items for January, 1972. The key to food item code numbers is presented in Table 34.

n = 88 FDI = 19.49%


PERCENTAGE OCCURRENCE IN SAMPLE (HISTOGRAM)
AVERAGE NUMBER OF POINTS PER OCCURRENCE
PERCENTAGE OF FOOD BY VOLUME
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
FOOD ITEMS

certain food items and their frequency of occurrence. For example, high average points were most often associated with large food items which occurred only infrequently. As was indicated for the October 1971 sample, this provides evidence of opportunism and effective predation in the feeding of red cod. Such evidence for all other months is presented in Figures 34-44. As no seasonal trends were obvious there is no further discussion on this aspect.

5.3 b i (2) November 1971, results and discussion

Results of feeding analyses are presented in Figure 35.

Percentage of food by volume and FDI

Dominant food items were sprat (10.53%), *Munida* (9.97%), ahuru (5.81%) and the natant decapod *Pontophilus pilosoides* (4.99%). Apart from *Munida*, the dominants were different for this month compared with October 1971.

The more important food categories were fishes (27.69%), reptant decapods (21.05%), unidentified (18.28%), and natant decapods (11.63%).

There were 36 food items present in the diet for this sample giving an FDI of 30.51%.

5.3 b i (3) December 1971, results and discussion

Results of feeding analyses are presented in Figure 36a.

Percentage of food by volume and FDI

Munida comprised 40.21% of the volume of the food, with the reptant decapods long-legged masking crab and policeman crab, and the fish *Arnoglossus scapha*, each comprising 7.22%.

With *Munida* so dominant in the food, reptant decapods were the most important food category, comprising 65.98% of all food taken. Next were fishes (16.49%), unidentified (10.30%), salps (4.12%), amphipods (2.06%), and isopods (1.03%).

The range of food taken during this month was very small (FDI of 15.25%) as was the total quantity. These features probably reflect in part the small size of the sample (44 fish).

5.3 b i (4) January 1972, results and discussion

Results of feeding analyses are presented in Figure 36b.

FIGURE 37

Canterbury area feeding analyses by individual food items for February 1972. The key to food item code numbers is presented in Table 34.

n = 156 FDI = 25.42%

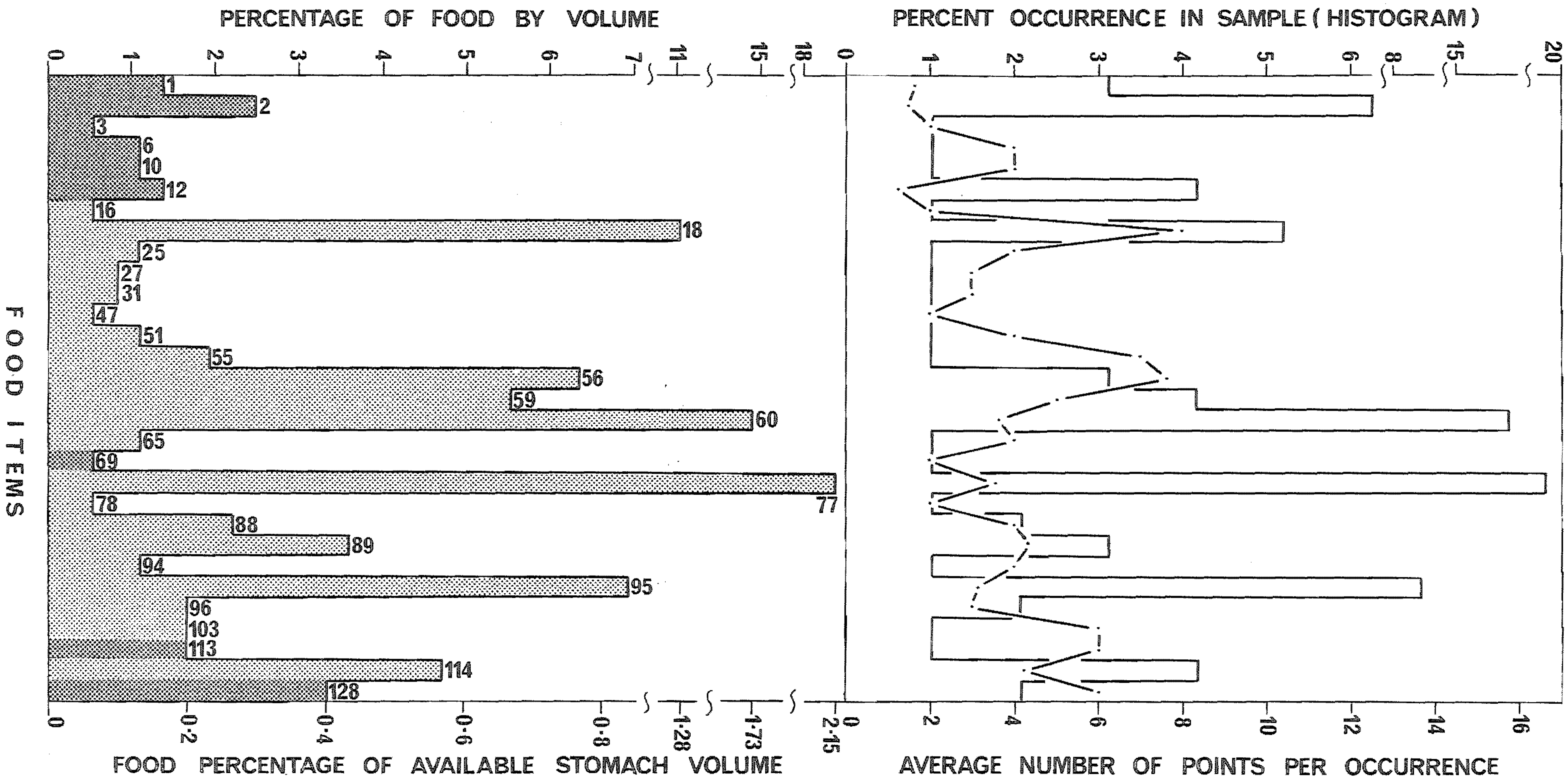

PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
1
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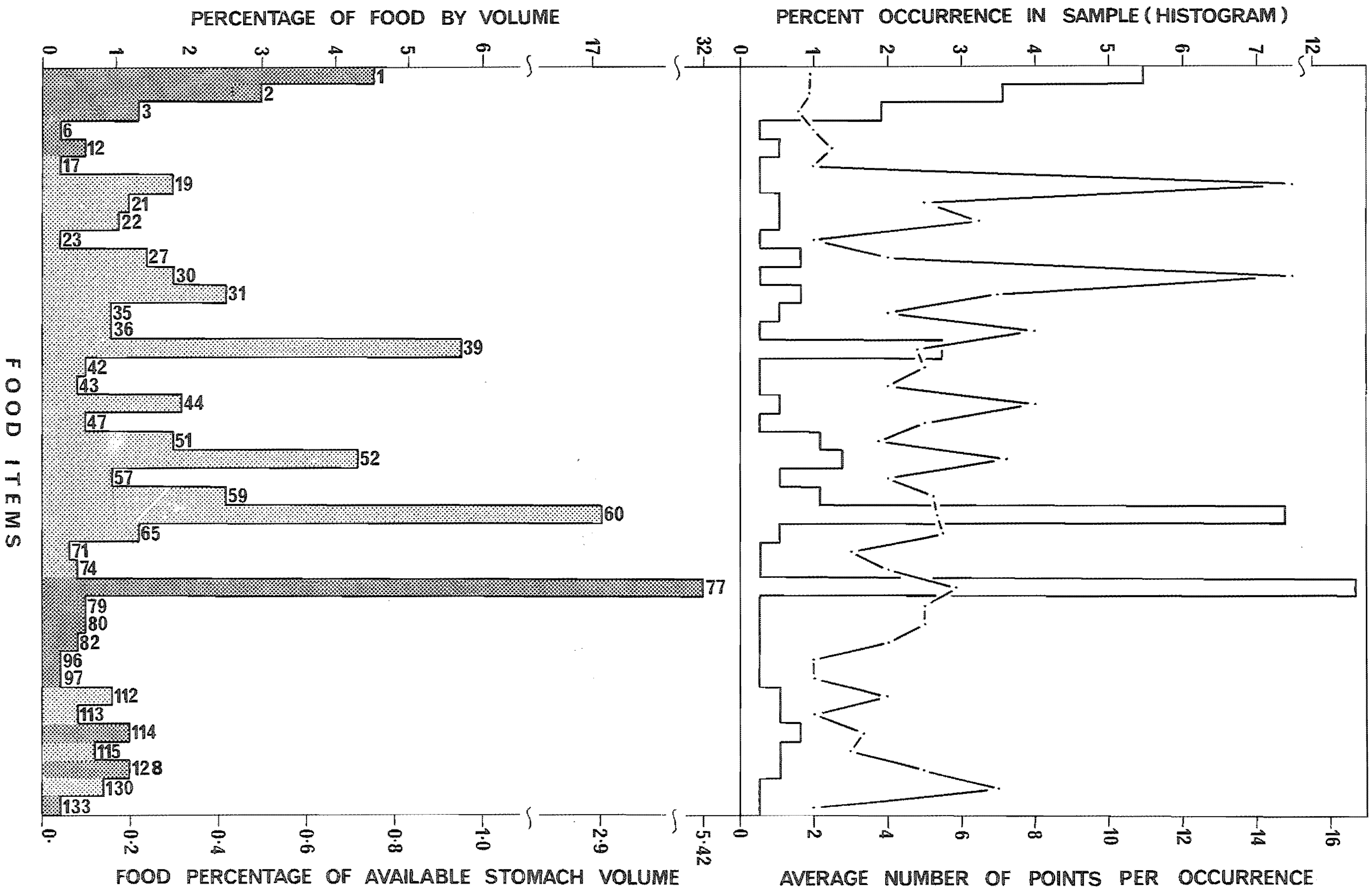
FIGURE 38

Canterbury area feeding analyses by individual food items for March 1972. The key to food item code numbers is presented in Table 34.

n = 248 FDI = 34.75%



PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
0 1 2 3 4 5 6 17 32
0 1 2 3 4 5 6 7 12
0· 0·2 0·4 0·6 0·8 1·0 2·9 5·42
0 2 4 6 8 10 12 14 16
1 2 3 6 12 17 19 21 22 23 27 30 31 35 36 39 42 43 44 47 51 52 57 59 60 65 71 74 77 79 80 82 96 97 112 113 114 115 128 130 133

Percentage of food by volume and FDI

Fishes or fish remains comprised the bulk of the food in this sample. The more important were bluebonnet (18.13%), pilchard (13.47%), opal-fish (9.33%), fish remains (7.77%), and red gurnard (6.22%). Fishes was the dominant food category (62.18%), followed by unidentified (20.73%), amphipods (6.7%), reptant decapods (4.14%), and stomatopods and mysids, each representing 2.07% of food. Also present were echinoderms (1.55%), and urochordates (0.52%).

Munida, which made up such a large part of the food of previous samples, comprised only 1.55% of this sample. This is surprising as this species is usually a readily available food source at this time of the year (See December sample; also Graham, 1953; Williams, 1973a).

The range of food items for this month, as for December 1971, was small there being only 23 items present, giving a FDI of 19.49%.

5.3 b i (5) February 1972, results and discussion

Results of feeding analyses are presented in Figure 37.

Percentage of food by volume and FDI

Food items predominant in the red cod diet during this month were *Munida* (18.46%), bluebonnet (14.88%), silverside (11.02%), red swimming crab (6.89%), and black cod (6.34%). There were 25 other food items, 15 of which had individual volume representations of less than 1.5%. The FDI was 25.42%.

Fishes was the most important food category (45.74%), followed by reptant decapods (36.08%), unidentified (7.99%), euphausids (4.68%), molluscs (3.31), stomatopods (1.65%), and natant decapods (0.55%).

An unusual item in the food during this month was the black cod.

5.3 b i (6) March 1972, results and discussion

Results and feeding analyses are presented in Figure 38.

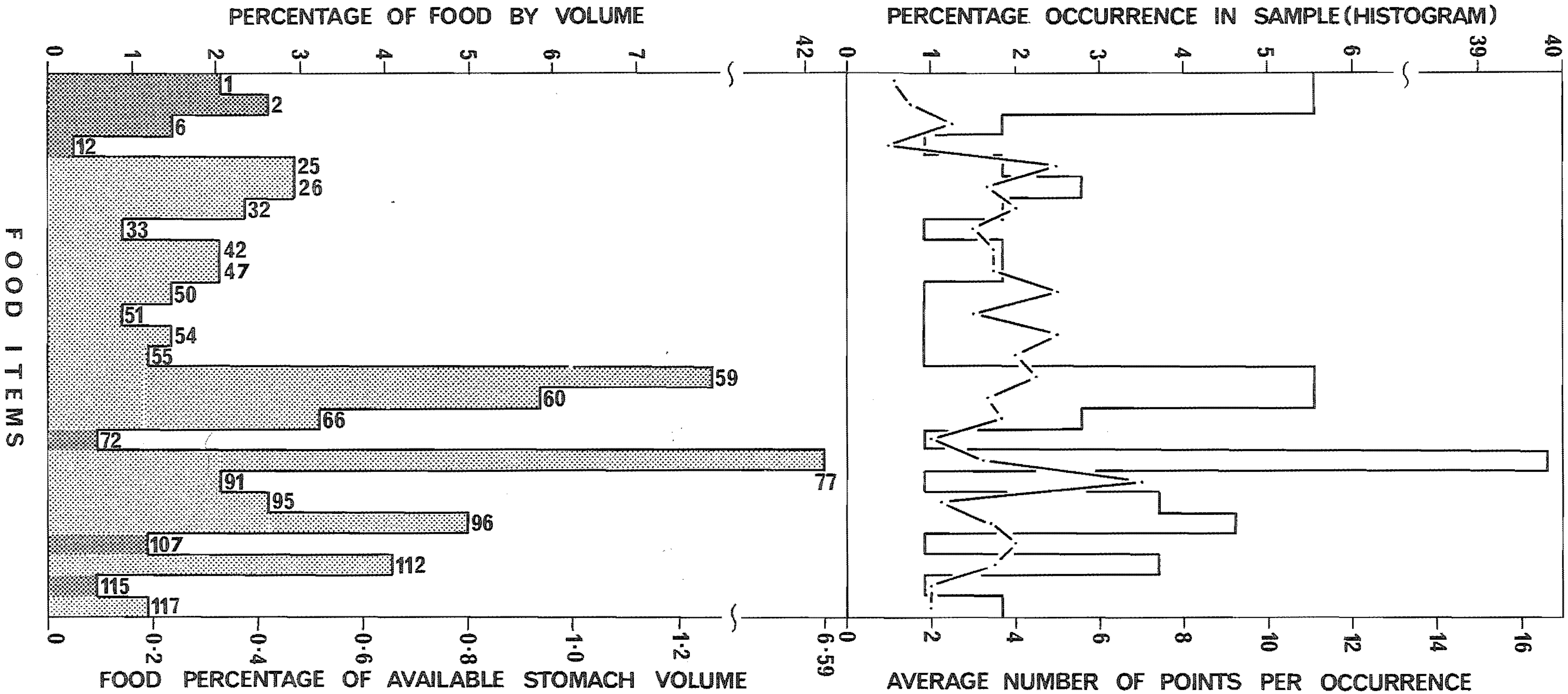
Percentage of food by volume and FDI

Munida was again an important item in the food (31.99%), together with bluebonnet (17.12%), witch (5.71%), and unidentified remains (4.52%). The most important food categories were fishes (49.82%), reptant

FIGURE 39

Canterbury area feeding analyses by individual food items for April 1972. The key to food item code numbers is presented in Table 34.

n = 107 FDI = 22.03%



PERCENTAGE OF FOOD BY VOLUME
PERCENTAGE OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
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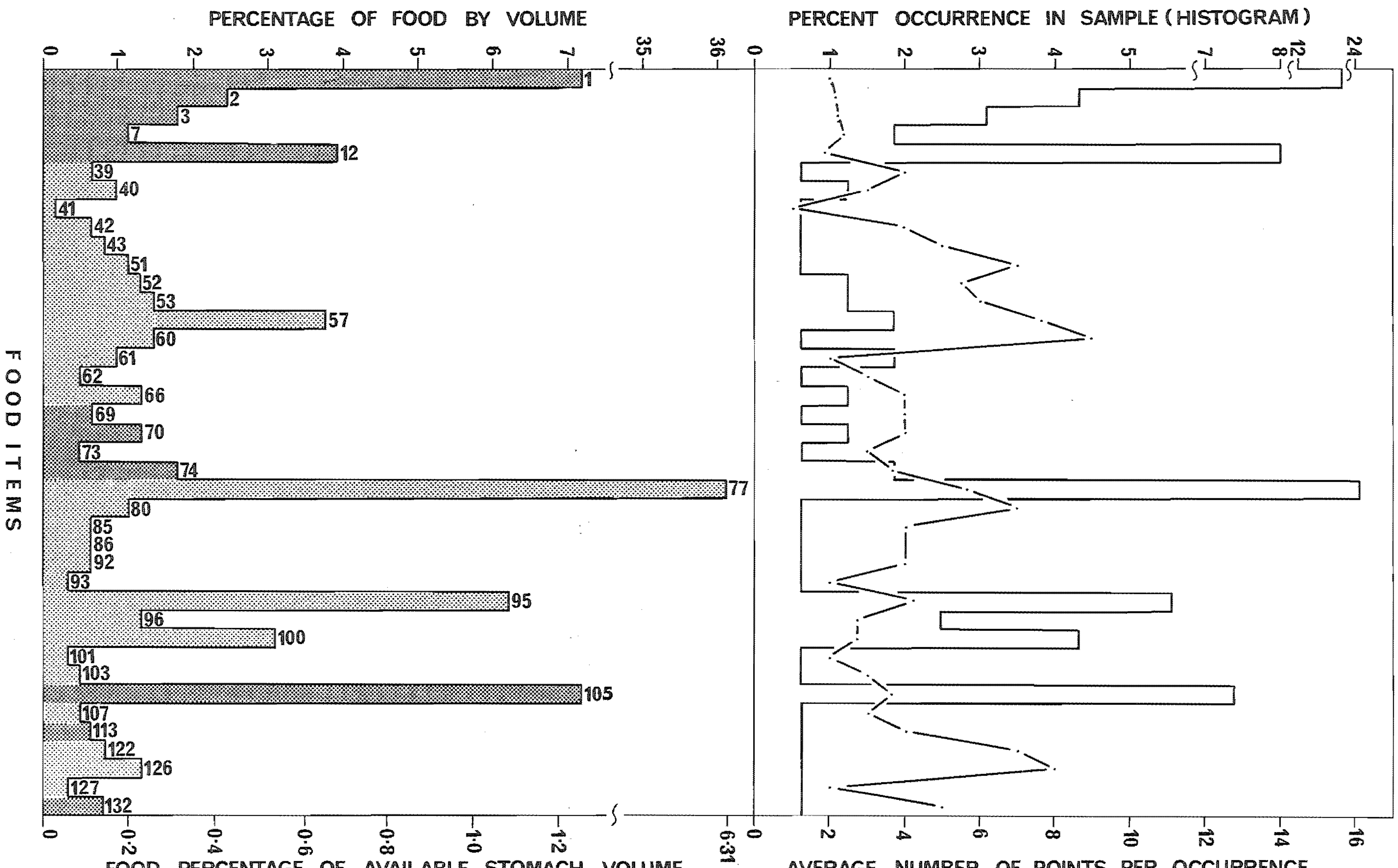
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE

FIGURE 40

Canterbury area feeding analyses by individual food items for May 1972. The key to food item code numbers is presented in Table 34.

n = 175 FDI = 33.90%

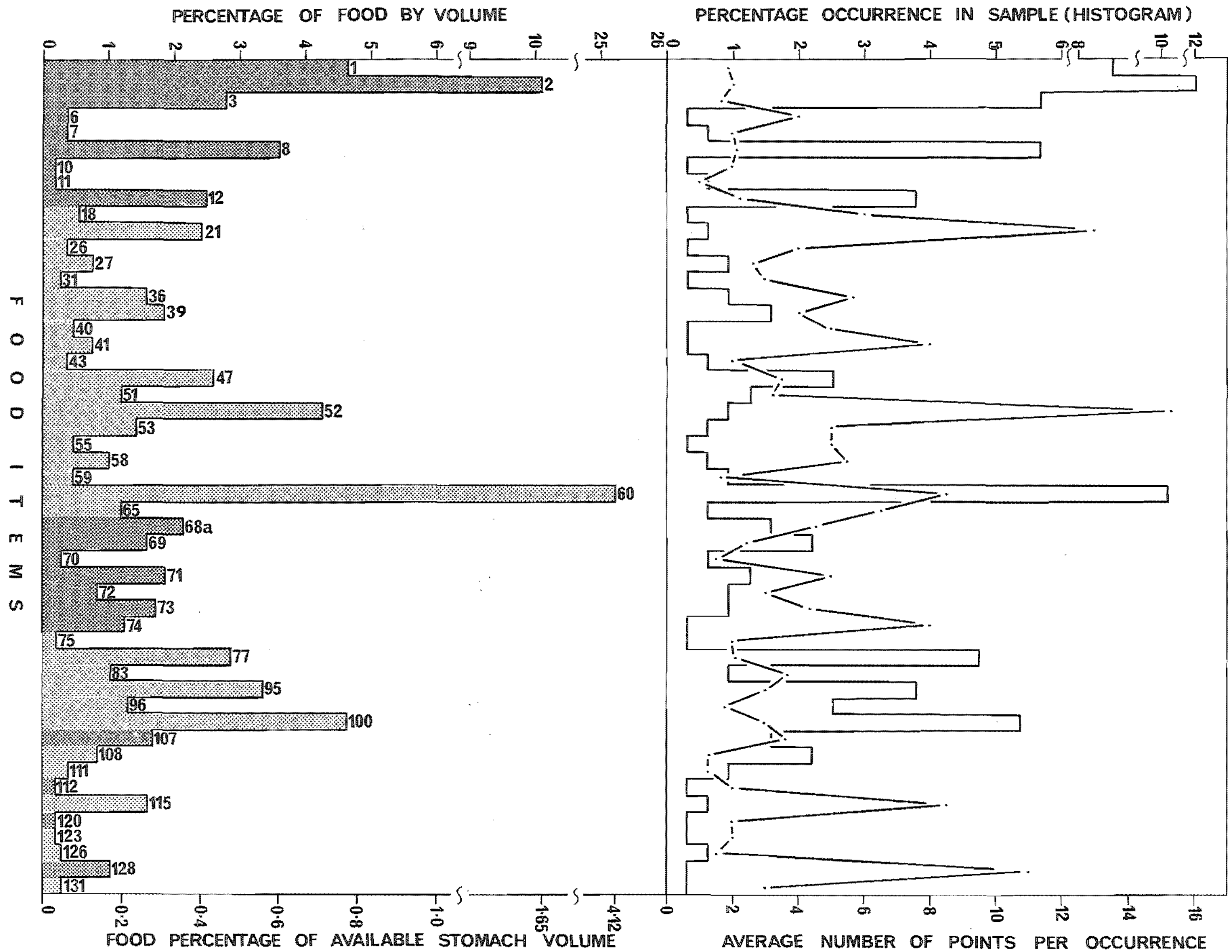


PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE

FIGURE 41

Canterbury area feeding analyses by individual food items for June 1972. The key to food item code numbers is presented in Table 34.

n = 330 FDI = 43.22%



PERCENTAGE OF FOOD BY VOLUME
PERCENTAGE OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
0 1 2 3 4 5 6 9 10 25 26
0 1 2 3 4 5 6 8 10 12
0 0·2 0·4 0·6 0·8 1·0 1·65 4·12
0 2 4 6 8 10 12 14 16
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decapods (34.13%), and unidentified (9.63%). Lesser categories were stomatopods (1.43%), euphausids (1.19%), molluscs (1.19%), natant decapods (0.84%), echinoderms (0.83%), mysids (0.71%), and salps (0.24%).

A relatively large range of food items (41) was present in this sample which had an FDI of 34.75%. This may simply reflect the large size of the sample.

5.3 b i (7) April 1972, results and discussion

Results of feeding analyses are presented in Figure 39.

Percentage of food by volume and FDI

Food items present in the largest quantity were *Munida* (41.23%), opalfish (7.90%), bluebonnet (5.85%), and the common swimming crab (4.97%). In terms of categories, the most important was reptant decapods (50.88%). This was followed in importance by fishes (35.10%), unidentified (6.43%), stomatopods (4.09%), amphipods (1.17%), molluscs (1.17%), natant decapods (0.58%), and mysids (0.58%).

There were 26 items of food in this sample, yielding an FDI of 22.03%.

5.3 b i (8) May 1972, results and discussion

Results of feeding analyses are presented in Figure 40.

Percentage of food by volume and FDI

Dominant food items were *Munida* (36.11%), unidentified remains (7.19%), and the amphipod *Ampelisca chiltoni* (7.19%). The remaining 37 food items were present in only small quantities (FDI of 33.90%). Food categories in decreasing order of importance were reptant decapods (51.46%), unidentified (16.50%), fishes (16.17%), amphipods (7.19%), natant decapods (4.25%), molluscs (2.46%), urochordates (0.82%), stomatopods (0.65%), and isopods (0.49%).

A notable item in the food was *A. chiltoni*. Although present in many other monthly samples, this was the first time that it achieved any degree of importance.

5.3 b i (9) June 1972, results and discussion

Results of feeding analyses are presented in Figure 41.

FIGURE 42

Canterbury area feeding analyses by individual food items for July 1972. The key to food item code numbers is presented in Table 34.

n = 210 FDI = 38.14%

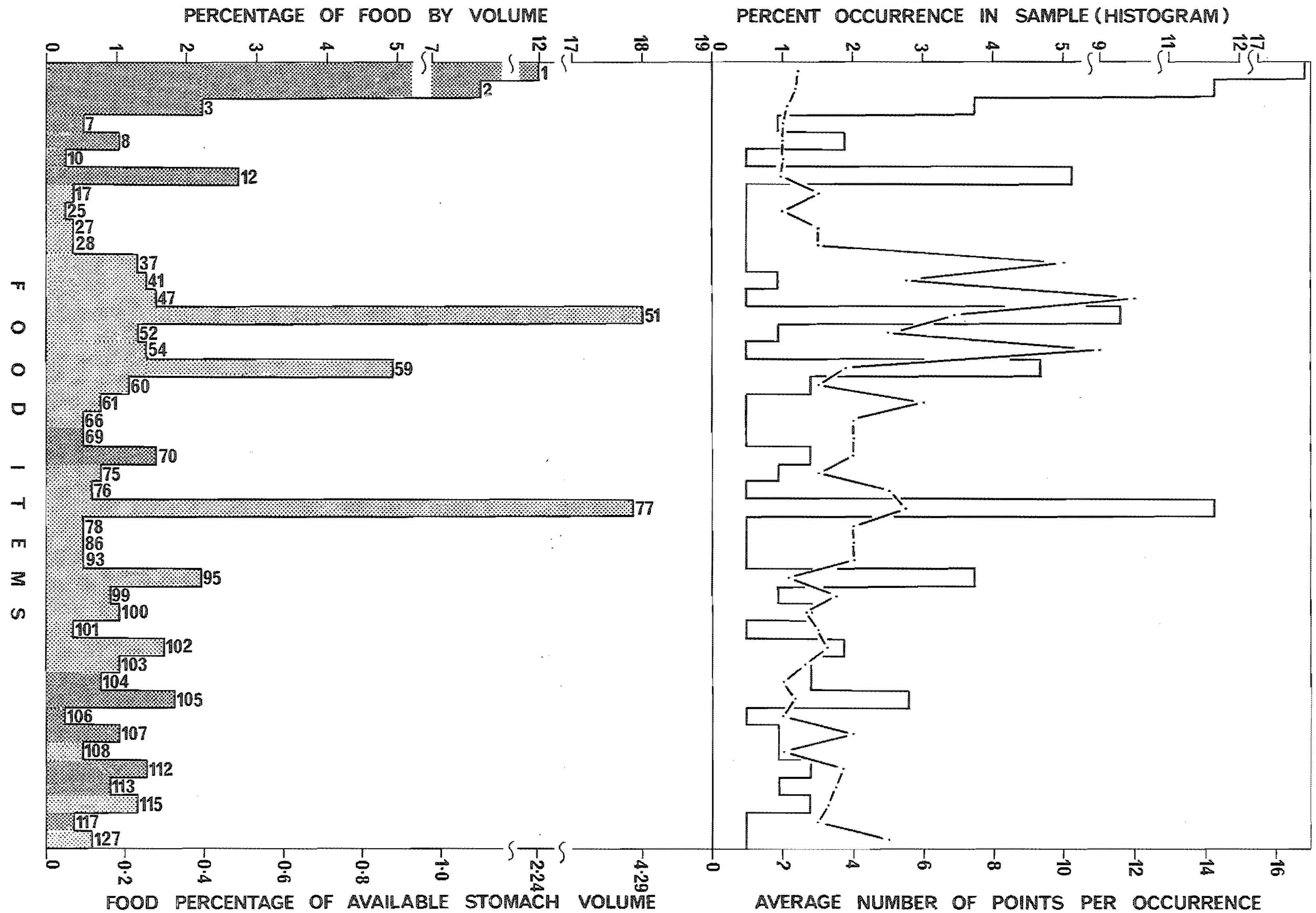
PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE
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FIGURE 43a

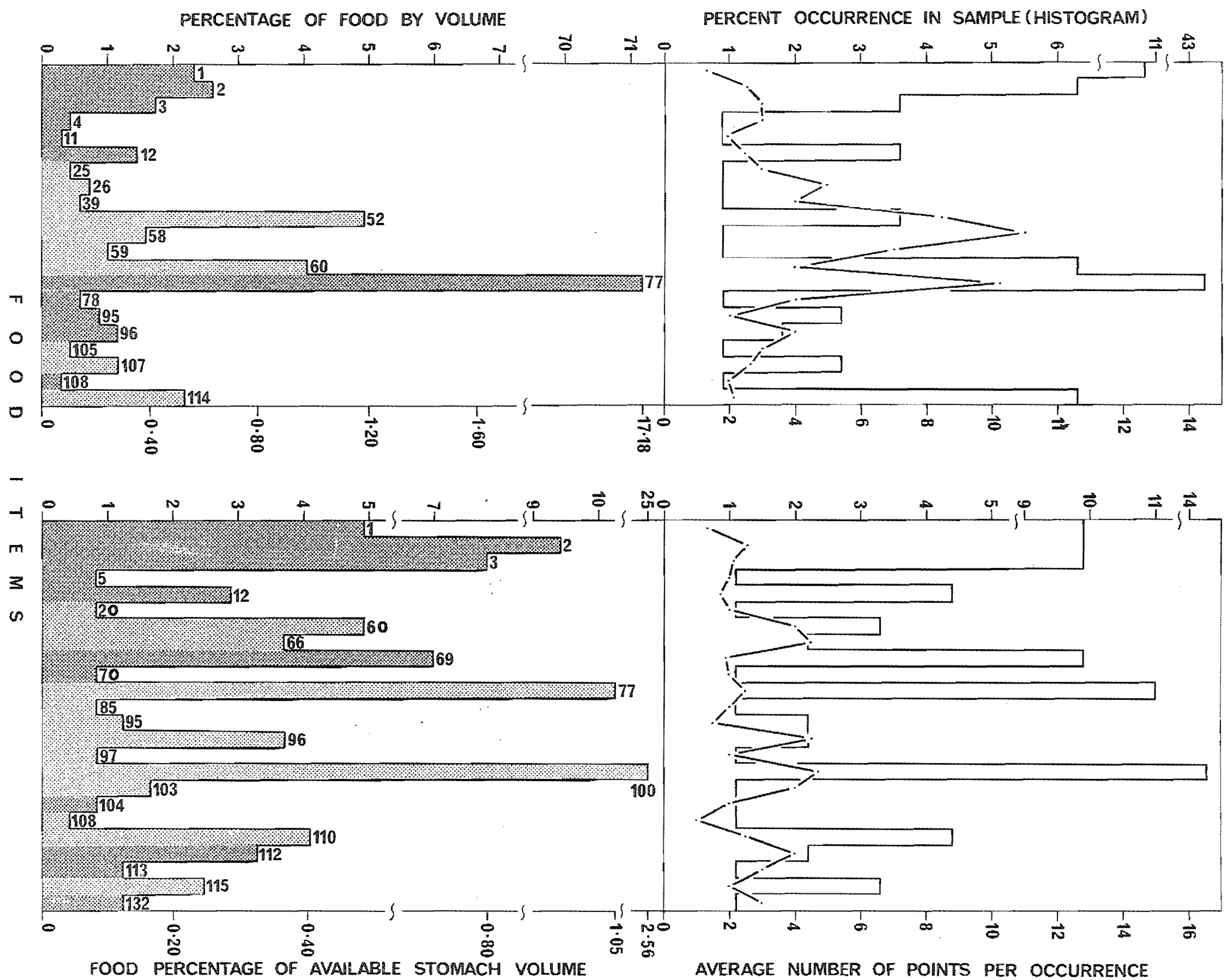
Canterbury area feeding analyses by individual food items for August 1972. The key to food item code numbers is presented in Table 34.

n = 143 FDI = 17.80%

FIGURE 43b

Canterbury area feeding analyses by individual food items for September 1972. The key to food item code numbers is presented in Table 34.

n = 119 FDI = 20.34%


PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE

Percentage of food by volume and FDI

This big sample (330 fish) contained a relatively large range of food items (FDI of 43.22%). However, apart from bluebonnet (25.21%), and unidentified fish remains (10.10%), items were present in only small quantities. Almost half the items had individual percentage volumes of less than 1%. *Munida*, which was so dominant in earlier samples, comprised only 2.85% of the food in this sample.

Food categories in decreasing order of importance were fishes (46.90%), unidentified (24.24%), reptant decapods (15.02%), natant urochordates (0.28%), and stomatopods (0.19%).

5.3 b i (10) July 1972, results and discussion

Results of feeding analyses are presented in Figure 42.

Percentage of food by volume and FDI

Three food items comprised almost half the total volume of food in this sample. These were seaperch (17.99%), *Munida* (17.86%), and unidentified remains (12.26%). Of the remaining items, half had individual percentage volumes of less than 1%. With the influence of the above three dominant foods, it is not surprising that the dominant food categories were fishes (33.86%), reptant decapods (28.14%), and unidentified (26.73%). Other categories present in decreasing order of importance were amphipods (3.91%), stomatopods (2.34%), natant decapods (2.08%), mysids (1.30%), molluscs (1.04%), and isopods (0.52%).

There were 45 food items present in this sample giving a FDI of 38.14%.

5.3 b i (11) August 1972, results and discussion

Results of feeding analyses are presented in Figure 43a.

Percentage of food by volume and FDI

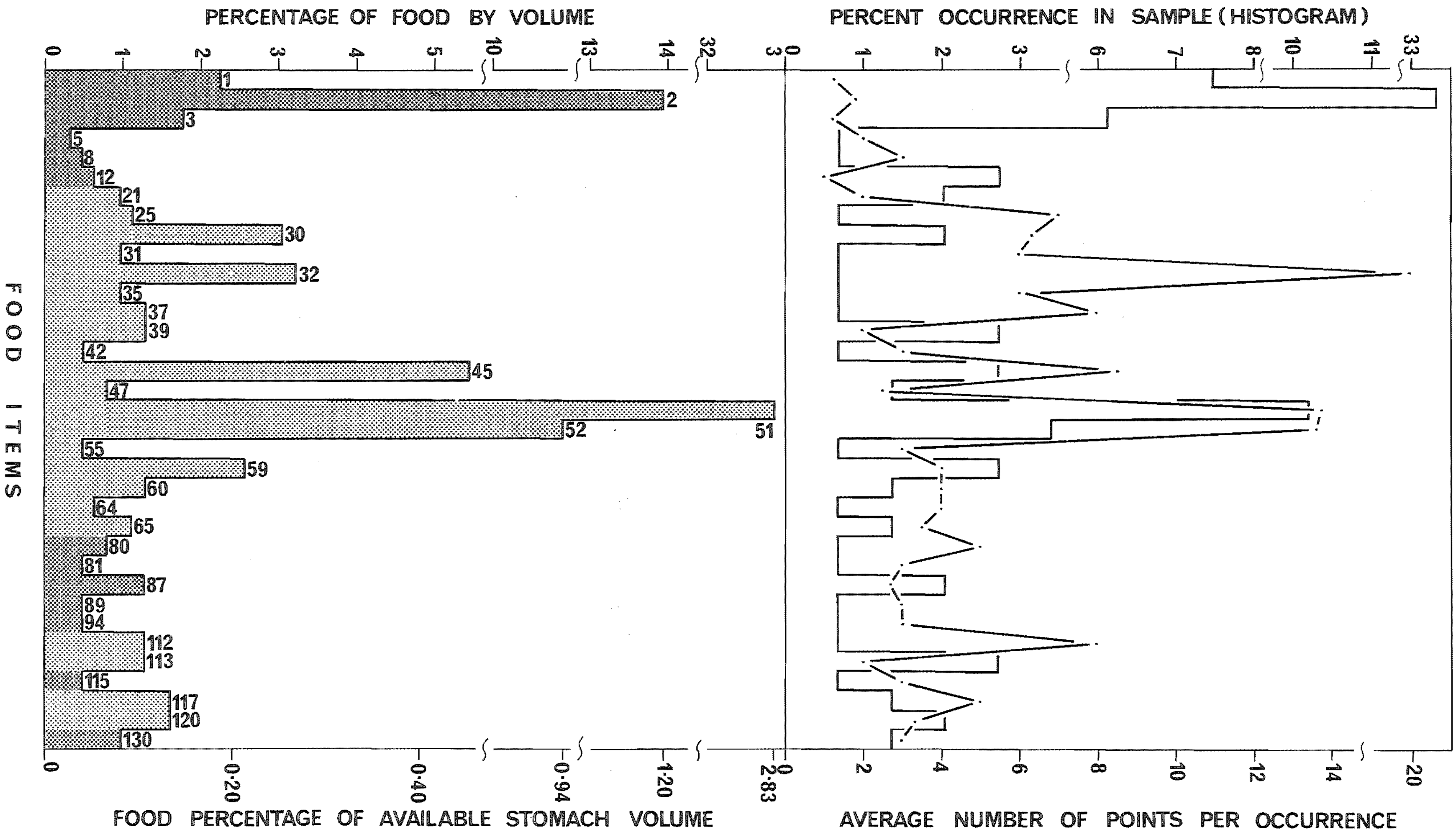
Of the small range of food items in this sample (21, FDI of 17.80%), the most important was *Munida*, which comprised 71.16% of all food. All other items, apart from tarakihi (4.93%), and bluebonnet (4.05%), were quite insignificant.

The most important food category was reptant decapods (73.77%). This was followed in decreasing order of importance by fishes (13.52%),

FIGURE 44

Canterbury area feeding analyses by individual food items for October 1972. The key to food item code numbers is presented in Table 34.

n = 362 FDI = 29.66%


PERCENTAGE OF FOOD BY VOLUME
PERCENT OCCURRENCE IN SAMPLE (HISTOGRAM)
FOOD ITEMS
FOOD PERCENTAGE OF AVAILABLE STOMACH VOLUME
AVERAGE NUMBER OF POINTS PER OCCURRENCE

unidentified (8.84%), euphausids (2.17%), amphipods (1.59%), and isopods (0.29%).

5.3 b i (12) September 1972, results and discussion

Results of feeding analyses are presented in Figure 43b.

Percentage of food by volume and FDI

The more important food items in this sample were the tunneling mud crab *Helice crassa* (25.00%), *Munida* (10.25%), unidentified fish remains (9.43%), unidentified crustacean remains (7.79%), *Pontophilus australis* (6.97%), unidentified remains (4.92%), and bluebonnet (4.92%).

Food categories in decreasing order of importance were reptant decapods (43.45%), unidentified (25.83%), fishes (9.43%), natant decapods (7.79%), isopods (4.51%), stomatopods (4.51%), mysids (2.64%), urochordates (1.22%), and amphipods (0.80%).

In a sample of 119 fish, there were 24 food items, yielding a FDI of 20.34%.

5.3 b i (13) October 1972, results and discussion

Results of feeding analyses are presented in Figure 44.

Percentage of food by volume and FDI

Dominant food items in this sample were seaperch (32.85%), unidentified fish remains (13.94%), and tarakihi (10.90%). There were 32 other items present, all of which occurred in only small quantities. The FDI for this month was low (29.66%) considering the size of the sample (362).

Food categories present in decreasing order of importance were fishes (69.37%), unidentified (19.38%), reptant decapods (3.52%), molluscs (3.20%), stomatopods (2.56%), echinoderms (0.96%), and mysids (0.48%).

A point of interest is that this was the only sample taken from the Canterbury area which did not contain *Munida*.

5.3 b i (14) General discussion - Canterbury samples

There were 118 food items in the diet of red cod in the Canterbury samples. The only items listed in Table 34 which were not present were numbers 13-15, 29, 34, 46, 48-49, 63, 84, 90, 98, 116, 118, 121 and 124.

Munida was the most prevalent item. In seven of the thirteen monthly samples, this species was the dominant food. Comprising up to 71.16% of the food, *Munida* had an average percentage volume of 25.27% for all samples. As was noted above, it was absent from only one sample (October 1972).

The prevalence of *Munida* in the diet of the red cod is interesting because *Munida* undergoes seasonal movements from the sea bottom into surface waters (Williams, 1973a). Obviously, red cod must perform similar movements to ensure a continuing supply of *Munida*.

Walker (1972) found that another species of *Munida, M. haswelli*, constitutes a major food for the Australian southern rock cod, a species closely related to the red cod (See Section 2).

Other items of importance in the red cod diet were bluebonnet (average for all samples 7.24%), unidentified fish remains (5.23%), unidentified remains (4.86%), seaperch (4.69%), and opalfish (2.63%).

Items which achieved importance in some samples were the red cod and common swimming crabs, policeman crab, long-legged masking crab, tunneling mud crab, tarakihi, ahuru, silverside, black cod, pilchard, witch, red gurnard, the natant decapod *Pontophilus pilosoides*, and the amphipod *Ampelisca chiltoni*. There was little evidence of any pattern of change in food items taken from month to month.

The main food categories were fishes, reptant decapods, unidentified, and to a lesser extent, natant decapods.

Variability in the diet, as indicated by the FDI, was related more or less directly to the size of the samples, although there were variations within this relationship. The largest FDIs occurred in June and July 1972 (sample sizes of 330 and 210 fish), the smallest in December 1971 (sample size 44). However, the very large October 1972 sample (362 fish) yielded only a moderate FDI. Because of the variation in sample size, no further comparisons were possible.

5.3 b ii Otago samples by month (See also Tables 28 and 34)

5.3 b ii (1) May 1971, results and discussion

Results of feeding analyses are presented in Table 35.

Table 35: Feeding analyses of red cod stomach contents, Otago, May 1971.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	2 (5.13%)	2	1.61	0.26
2	4 (10.26%)	8	6.45	1.03
3	1 (2.56%)	1	0.81	0.13
7	2 (5.13%)	2	1.61	0.26
12	1 (2.56%)	2	1.61	0.26
53	1 (2.56%)	4	3.23	0.51
57	1 (2.56%)	7	5.56	0.90
58	3 (7.69%)	9	7.26	1.15
59	1 (2.56%)	2	1.61	0.26
62	1 (2.56%)	2	1.61	0.26
64	1 (2.56%)	5	4.03	0.64
66	1 (2.56%)	4	3.23	0.51
77	1 (2.56%)	3	2.45	0.38
95	2 (5.13%)	4	3.23	0.51
97	11 (28.21%)	42	33.87	5.38
107	2 (5.13%	7	5.65	0.90
112	1 (2.56%)	12	9.68	1.54
115	1 (2.56%)	3	2.42	0.38
117	1 (2.56%)	4	3.23	0.51
121	1 (2.56%)	1	0.81	0.13
n = 39				

Food items which were most prevalent in the diet of red cod during this month were policeman crab (33.87% of food by volume), the stomatopod *Squilla armata* (9.68%), and southern kingfish (7.26%).

Food categories in decreasing order of importance were reptant decapods (39.55%), fishes (26.62%), unidentified (12.09%), stomatopods (9.68%), amphipods (5.65%), molluscs (4.04%), and mysids (2.40%).

These findings may be compared with those of the Canterbury area for May. The main food items were quite different. *Munida*, which comprised 36.11% of the food in the Canterbury sample, only comprised 2.45% of the food in the Otago sample. Conversely, the policeman crab, so important in the diet of Otago red cod, did not even occur in the food of Canterbury fish.

However, the most important food categories were the same in both areas.

Only 15.90% of the available stomach volume was occupied by food in this small sample.

5.3 b ii (2) November 1971, results and discussion

Results of feeding analyses are presented in Table 36.

Table 36: Feeding analyses of red cod stomach contents, Otago, November 1971.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	29 (15.03%)	56	7.68	2.19
2	12 (6.22%)	25	3.43	0.98
3	9 (4.66%)	16	2.19	0.62
4	1 (0.52%)	1	0.14	0.04
5	1 (0.52%)	2	0.27	0.08
7	2 (1.04%)	2	0.27	0.08
8	1 (0.52%)	4	0.54	0.16
11	1 (0.52%)	1	0.14	0.04
12	4 (2.07%)	7	0.96	0.27
14	1 (0.52%)	8	1.10	0.31
15	1 (0.52%)	11	0.51	0.43
17	2 (1.04%)	7	0.96	0.27
18	2 (1.04%)	18	2.47	0.70
19	13 (6.74%)	46	6.31	1.80
28	2 (1.04%)	6	0.82	0.23
33	3 (1.55%)	9	1.23	0.35
54	2 (1.04%)	6	0.82	0.23
59	2 (1.04%)	13	1.78	0.51
61	1 (0.52%)	3	0.41	0.12
62	2 (1.04%)	5	0.61	0.20
63	1 (0.52%)	12	1.65	0.47
68a	1 (0.52%)	2	0.27	0.08
69	2 (1.04%)	11	1.51	0.43

Table 36: Continued

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
77	48 (24.87%)	285	39.09	11.13
78	1 (0.52%)	2	0.27	0.08
95	4 (2.07%)	11	1.51	0.43
96	4 (2.07%)	17	2.33	0.66
97	18 (9.33%)	71	9.74	2.77
99	2 (1.04%)	6	0.82	0.23
102	2 (1.04%)	9	1.23	0.35
103	1 (0.52%)	7	0.96	0.27
105	1 (0.52%)	1	0.14	0.04
107	2 (1.04%)	4	0.54	0.16
112	2 (1.04%)	5	0.69	0.20
116	2 (1.04%)	4	0.54	0.16
121	1 (0.52%)	2	0.27	0.08
122	1 (0.52%)	3	0.41	0.12
124	1 (0.52%)	5	0.69	0.20
128	5 (2.59%)	18	2.47	0.70
129	3 (1.55%)	8	1.10	0.31
n = 128				

This sample, which was considerably larger than the May sample, contained twice as many food items. The most important were *Munida* (39.09%), policeman crab (9.74%), unidentified remains (7.68%), and smelt (6.31%).

Food categories in decreasing order of importance were reptant decapods (55.95%), fishes (19.75%), unidentified (15.62%), molluscs (4.38%), natant decapods (1.78%), annelids (1.15%), stomatopods (0.69%), and amphipods (0.68%).

Comparing these findings with the November Canterbury sample findings, in both, *Munida* was a dominant food. But, as for the May comparison, policeman crab, important for Otago cod, was absent from Canterbury samples.

The more important food categories were similar in samples from both areas.

Some 28.48% of the available stomach volume was occupied by food in this sample.

5.3 b ii (3) February 1972, results and discussion

Results of feeding analyses are presented in Table 37.

Table 37: Feeding analyses of red cod stomach contents, Otago, February 1972.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	8 (8.00%)	16	3.86	0.88
2	1 (1.00%)	1	0.24	0.05
3	9 (9.00%)	27	6.51	1.48
7	2 (2.00%)	6	1.45	0.33
19	1 (1.00%)	2	0.48	0.11
68a	8 (8.00%)	37	8.92	2.03
69	8 (8.00%)	44	10.60	2.42
77	2 (2.00%)	6	1.45	0.33
87	1 (1.00%)	2	0.48	0.11
89	1 (1.00%)	2	0.48	0.11
99	1 (1.00%)	2	0.48	0.11
100	6 (6.00%)	19	4.58	1.04
103	1 (1.00%)	3	0.72	0.16
197	28 (28.00%)	140	33.73	5.71
113	1 (1.00%)	9	2.17	0.49
114	8 (8.00%)	26	6.26	1.43
115	14 (14.00%)	73	17.59	4.01
n = 91				

Of the 17 different food items present in this sample, the most important was the amphipod *Ampelisca chiltoni* which comprised 33.73% of the food. Next in importance were the opossum shrimp *Australomysis* sp. (17.59%), and the natant decapods *Pontophilus australis* (10.60%), and *Palaemon affinis* (8.92%).

Food categories in decreasing order of importance were amphipods (33.73%), natant decapods (19.52%), mysids (17.59%), unidentified (12.06%), reptant decapods (8.19%), euphausids (6.26%), stomatopods

(2.17%), and fishes (0.48%).

The bulk of the food (95.42%) therefore consisted of invertebrates. This was typical for small red cod in all samples (the size range of red cod in this sample was 5-20 cm TL - see Fig. 27).

The May and November samples from this area consisted of larger red cod (See Fig. 27). In these samples, larger food items were more important. For example, fishes and fish remains, which represented only 0.72% of the food in the February sample, represented 33.07% in the May sample, and 23.18% in the November sample.

Similarly, the February sample from the Canterbury area consisted of larger red cod (See Fig. 26). Fishes and fish remains represented 48.24% of the food in this sample.

5.3 b ii (4) General discussion - Otago samples

There were 42 food items in the diet of red cod from Otago waters. Apart from the elasmobranchs spotted smoothhound and elephant fish, and the mollusc Maurea top shell, all items also occurred in the Canterbury samples.

The most notable feature was the dominance of the invertebrates policeman crab, *Munida*, and *Ampelisca* in the food of Otago cod.

5.3 b iii Foveaux Strait sample November 1971, results and discussion (See also Tables 29 and 34)

Results of feeding analyses are presented in Table 38.

Table 38: Feeding analyses of red cod stomach contents, Foveaux Strait, November 1971.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	31 (20.81%)	39	13.49	1.60
2	15 (10.07%)	18	6.23	0.74
5	1 (0.67%)	1	0.35	0.04
8	2 (1.34%)	4	1.38	0.16
12	12 (8.05%)	17	5.88	0.70
13	1 (0.67%)	2	0.69	0.08
17	6 (4.03%)	13	4.50	0.53

Table 38: Continued

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
32	1 (0.67%)	4	1.38	0.16
40	3 (2.01%)	13	4.50	0.53
64	1 (0.67%)	2	0.69	0.08
69	4 (2.68%)	10	3.46	0.41
74	2 (1.34%)	6	2.08	0.25
77	61 (40.94%)	135	46.71	5.53
96	5 (3.36%)	13	4.50	0.53
97	2 (1.34%)	6	2.08	0.25
112	1 (0.67%)	2	0.69	0.08
128	1 (0.67%)	3	1.04	0.13
n = 122				

Some of the more important items of food in this sample were *Munida* (46.71%), unidentified remains (13.49%), unidentified fish remains (6.23%), debris (5.88%), and sprat, sand flounder and common swimming crab, all with 4.50%. There were 17 items present and these occupied only 11.78% of the available stomach volume.

Food categories in decreasing order of importance were reptant decapods (53.29%), unidentified (27.38%), fishes (11.76%), natant decapods (5.54%), molluscs (1.34%), and stomatopods (0.69%).

This sample was similar to the Canterbury and Otago November samples in that *Munida* was the dominant food. However, this sample also contained a large percentage of unidentified material. This was mainly owing to advanced digestion in many of the stomachs.

There was only one food item present in the Foveaux Strait sample which was not present in the Canterbury samples. This was the spotted spiny dogfish. This species was also absent from the food of Otago samples as were red cod, sand flounder, *Sergestes potens*, common swimming crab, and octopus.

5.3 b iv W.C.S.I. sample March 1972, results and discussion (See also Tables 30 and 34)

Results of feeding analyses are presented in Table 39.

Table 39: Feeding analyses of red cod stomach contents, W.C.S.I., March 1972.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	3 (2.13%)	6	0.56	0.14
2	15 (10.64%)	40	3.77	0.95
3	4 (2.84%)	4	0.38	0.10
12	2 (1.42%)	3	0.28	0.07
21	10 (7.09%)	109	10.26	2.60
26	3 (2.13%)	11	1.04	0.26
30	22 (15.60%)	220	20.72	5.24
31	15 (10.64%)	138	12.99	3.29
32	5 (3.55%)	41	3.86	0.98
35	3 (2.13%)	25	2.45	0.60
37	3 (2.13%)	21	1.98	0.50
38	3 (2.13%)	27	2.54	0.64
39	1 (0.71%)	8	0.75	0.19
44	1 (0.71%)	12	1.13	0.29
45	4 (2.84%)	34	3.20	0.81
46	8 (5.67%)	74	6.97	1.76
47	2 (1.42%)	29	2.73	0.69
48	2 (1.42%)	15	1.41	0.36
51	7 (4.96%)	99	9.32	2.36
52	4 (2.84%)	22	2.07	0.52
55	2 (1.42%)	11	1.04	0.26
60	6 (4.26%)	36	3.39	0.86
63	1 (0.71%)	10	0.94	0.24
68b	3 (2.13%)	18	1.69	0.43
72	1 (0.71%)	9	0.85	0.21
97	10 (7.09%)	34	3.20	0.81
112	1 (0.71%)	6	0.56	0.14

n = 210

Five of the 27 items in this sample made up over 60% of the volume of food. These were the fishes hoki (20.72%), whiting (12.99%), lanternfish (10.26%), seaperch (9.32%), and silverfish (6.97%). The food category fishes therefore dominated the diet (88.69%). Other food categories present were unidentified (4.99%), reptant decapods (3.20%), natant decapods (2.54%), and stomatopods (0.58%).

Of the volume of stomach available for food in this sample, only 18.30% was utilized.

This sample may be compared with that of the Canterbury area for March 1972. Fishes were also dominant in the Canterbury sample (49.82%). However, different species of fish were dominant in the two areas.

Food items present in the W.C.S.I. sample and not in any of the Canterbury samples were silverfish, frostfish, and ling. Similarly, some items of W.C.S.I. food were absent from Otago samples, and the Foveaux Strait sample. In both cases, there were many such items. Therefore, only food item code numbers are listed. Reference may be made to Table 34 for the key to the code. Those absent from Otago samples were numbers 21, 26, 30, 31, 32, 35, 37, 38, 39, 44, 45, 46, 47, 48, 51, 52, 55, 60, 68b and 72. Those absent from the Foveaux Strait sample were 3, 21, 26, 30, 31, 35, 37, 38, 39, 44, 45, 46, 47, 48, 51, 52, 55, 60, 63, 68b and 72.

However, because of the small size of all these samples, it cannot be stated with any certainty that the items listed as being absent, would always be absent. For example, the seaperch, which was absent from the Otago samples of red cod in this study, was found in the stomachs of Otago red cod by Graham (1939a).

5.3 b v (1) September 1971, results and discussion

Results of feeding analyses are presented in Table 40.

Much of the food in this sample was unidentifiable (67.25% of food, 6.08% of available stomach volume). This was because digestion was well advanced.

Food items which could be recognised were pilchards (9.36% of food), tunneling mud crab (7.60%), *Nauticaris marionis* (6.43%), sprat (3.51%), *Australomysis* sp. (3.51%), red swimming crab (1.75%), and rounded sea spider (0.58%).

Table 40: Feeding analyses of red cod stomach contents, W.C.N.I., September 1971.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	10 (14.71%)	15	8.77	0.79
2	15 (22.06%)	48	28.07	2.53
3	19 (27.94%)	44	25.73	2.32
5	1 (1.47%)	2	1.17	0.11
8	2 (2.94%)	4	2.34	0.22
12	1 (1.47%)	2	1.17	0.11
16	2 (2.94%)	16	9.36	0.84
17	1 (1.47%)	6	3.51	0.32
73	5 (7.35%)	11	6.43	0.58
92	1 (1.47%)	1	0.58	0.05
95	1 (1.47%)	3	1.75	0.16
100	7 (10.29%)	13	7.60	0.68
115	3 (4.41%)	6	3.51	0.32
n = 95				

The September Canterbury sample similarly contained much food which was unidentifiable. Few other comparisons are possible.

Of the volume of stomach available in this sample, 9.03% was utilized for food.

5.3 b v (2) November 1971, results and discussion

Results of feeding analyses are presented in Table 41.

A very small range of foods was consumed by red cod in this sample, and much of the food (55.21%) was unidentified.

The most important recognisable food species were the ghost shrimp *Callianassa filholi* (9.37%) and the fishes ahuru and bluebonnet (both 7.29%).

Food categories in decreasing order of importance (apart from unidentified) were fishes (21.87%), reptant decapods (15.62%), and euphausids (7.29%).

Table 41: Feeding analyses of red cod stomach contents, W.C.N.I., November 1971.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	21 (55.26%)	36	37.50	3.75
2	1 (2.63%)	1	1.04	0.10
3	4 (10.53%)	10	10.42	1.04
8	3 (7.89%)	6	6.25	0.62
17	1 (2.63%)	2	2.08	0.20
33	1 (2.63%)	7	7.29	0.73
41	1 (2.63%)	5	5.21	0.52
60	1 (2.63%)	7	7.29	0.73
75	2 (5.26%)	9	9.37	0.94
77	1 (2.63%)	2	2.08	0.20
78	1 (2.63%)	4	4.17	0.42
114	1 (2.63%)	7	7.29	0.73
n = 48				

Of the volume of stomach available in this sample, only 9.98% was utilized for food.

Comparisons can be made between this sample and November samples from the Canterbury, Otago and Foveaux Strait areas. For example, *Munida*, which comprised such a large part of the food in the above area samples, was insignificant in the food in this W.C.N.I. sample (2.08% of food).

5.3 b v (3) October 1973, results and discussion

Results of feeding analyses are presented in Table 42.

Fishes were the most important food category in this sample (68.01% of food). Pilchards were the most prevalent item (32.67%). Other fishes present were common sole, sprat, leatherjacket, ahuru, and sand flounder.

Other categories of food present were unidentified (23.33%), isopods (3.33%), mysids (3.33%), and reptant decapods (2.00%).

Food occupied 12.50% of the available stomach volume.

Table 42: Feeding analyses of red cod stomach contents, W.C.N.I., October 1973.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	2 (5.71%)	2	1.33	0.17
2	4 (11.43%)	8	5.33	0.67
3	10 (28.57%)	25	16.67	2.08
16	4 (11.43%)	49	32.67	4.08
17	3 (8.57%)	16	10.67	1.33
33	1 (2.86%)	7	4.67	0.58
40	1 (2.86%)	3	2.00	0.25
43	3 (8.57%)	17	11.33	1.42
67	1 (2.86%)	10	6.67	0.83
96	1 (2.86%)	3	2.00	0.25
108	1 (2.86%)	3	2.00	0.25
109	1 (2.86%)	2	1.33	0.17
115	3 (8.57%)	5	3.33	0.42
n = 60				

This sample was very similar to that from the Canterbury area for October 1972. In both samples, fishes were predominant in the food, and the unidentified category came second in importance. However, the actual fish species of importance were different in the two areas. Those of importance in the Canterbury sample were seaperch and tarakihi and in the W.C.N.I. sample, pilchards. In both cases, red cod were utilizing a readily available food source (personal observations for Canterbury sample; see Baker, 1972, p. 18 regarding pilchards in the W.C.N.I. area).

5.3 b v (4) General discussion - W.C.N.I. samples

The samples collected from this area were generally inadequate for demonstrating the nature of food and feeding of the red cod. This was especially so owing to the large volumes of unidentified food in the September and November samples. However, the October sample indicated that the fishes pilchard, sprat, common sole and, to a lesser extent, leatherjacket, are prime food items.

The range of food items was small in all samples. In addition, food occupied only small percentages of the available stomach volume.

Comparisons are possible between samples from this area and others with regard to the presence or absence of various food items (e.g. See Section 5.3 b iv). However, suffice to say that many of the food items were found in all area samples, only in different proportions. This probably reflects the varying availability of the different items from area to area.

5.3 b vi C.B.C.C. samples by month (See also Tables 32 and 34)

5.3 b vi (1) February 1972, results and discussion

Results of feeding analyses are presented in Table 43.

Table 43: Feeding analyses of red cod stomach contents, C.B.C.C., February 1972.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
2	2 (25.00%)	3	25.00	0.79
12	1 (12.50%)	1	8.33	0.26
40	1 (12.50%)	2	16.67	0.53
93	1 (12.50%)	2	16.67	0.53
96	1 (12.50%)	2	16.67	0.53
103	2 (25.00%)	2	16.67	0.53
n = 19				

In this very small sample, only six food items were present. There was also very little food as only 3.17% of the available stomach volume was occupied by food. One-third of the food was unidentifiable. Therefore, little meaningful discussion is possible on food and feeding.

5.3 b vi (2) May 1972, results and discussion

Results of feeding analyses are presented in Table 44.

Predominant items in the food were *Ampelisca chiltoni* (12.81%), unidenfitied remains (10.00%), snapper (9.37%), *Munida* (8.75%), and *Allorchestes novizealandiae* (8.75%).

Table 44: Feeding analyses of red cod stomach contents, C.B.C.C., May 1972.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	20 (19.05%)	32	10.00	0.97
2	9 (8.57%)	24	7.50	0.73
3	19 (9.52%)	21	6.56	0.64
5	1 (0.95%)	2	0.62	0.06
8	1 (0.95%)	2	0.62	0.06
12	2 (1.90%)	3	0.94	0.10
19	2 (1.90%)	5	1.56	0.15
39	1 (0.95%)	4	1.25	0.12
43	1 (0.95%)	6	1.87	0.18
49	5 (4.76%)	30	9.37	0.91
50	1 (0.95%)	4	1.25	0.12
52	1 (0.95%)	8	2.50	0.24
60	4 (3.81%)	15	4.69	0.45
61	1 (0.95%)	2	0.62	0.06
66	1 (0.95%)	2	0.62	0.06
68	3 (2.86%)	10	3.12	0.30
77	10 (9.52%)	28	8.75	0.85
85	1 (0.95%)	4	1.25	0.12
89	1 (0.95%)	3	0.94	0.10
95	3 (2.86%)	5	1.56	0.15
106	8 (7.62%)	28	8.75	0.85
107	9 (8.57%)	41	12.81	1.24
108	3 (2.86%)	12	3.75	0.36
111	1 (0.95%)	1	0.31	0.03
112	2 (1.90%)	5	1.56	0.15
115	4 (3.81%)	23	7.19	0.70

n = 165

Food categories in decreasing order of importance were unidentified (26.24%), fishes (23.73%), amphipods (21.56%), reptant decapods (12.50%), mysids (7.19%), isopods (4.08%), natant decapods (3.14%), and stomatopods (1.56%).

Food occupied 9.70% of the available stomach volume.

Comparing this sample with the Canterbury sample for May, both contained *A. chiltoni* as a prominent food. Another invertebrate, policeman crab, was prominent in the corresponding Otago sample. All three areas had many of the same food items.

5.3 b vi (3) September 1972, results and discussion

Results of feeding analyses are presented in Table 45.

Table 45: Feeding analyses of red cod stomach contents, C.B.C.C., September 1972.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	2 (7.14%)	2	2.44	0.29
2	8 (28.57%)	21	25.61	3.00
3	5 (17.86%)	6	7.32	0.86
7	1 (3.57%)	1	1.22	0.14
12	2 (7.14%)	4	4.88	0.57
14	1 (3.57%)	4	4.88	0.57
66	1 (3.57%)	14	17.07	2.00
77	1 (3.57%)	3	3.66	0.43
93	1 (3.57%)	3	3.66	0.43
95	1 (3.57%)	3	3.66	0.43
112	1 (3.57%)	4	4.88	0.57
114	1 (3.57%)	3	3.66	0.43
115	2 (7.14%)	10	12.20	1.43
131	1 (3.57%)	4	4.88	0.57

n = 35

A large part of the food in this sample was unidentifiable (41.47%), mainly owing to the large quantity of fish remains (25.61%). Fishes were also prominent (21.95%), with red gurnard dominant (17.07%). The mysid *Australomysis* sp. was also important (12.20%). Other food categories present were reptant decapods (10.98%), stomatopods (4.88%), urochordates (4.88%), and euphausids (3.66%).

Food occupied 11.72% of the available stomach volume.

Few comparisons of any relevance can be made with other samples.

5.3 b vi (4) General discussion - C.B.C.C. samples

The most important food items in this area were the amphipods *Ampelisca chiltoni* and *Allorchestes novizealandiae*, *Munida*, the mysid *Australomysis* sp., and the fishes red gurnard and snapper.

The range of food items was generally small, although this might have been greater, had so much of the food not been unidentifiable. The range of items was most comparable with that of the Canterbury area. Only the spotted smoothhound and snapper were not common to the food of both areas, these items being absent from the Canterbury samples. The absence of snapper is understandable as Canterbury is south of this species normal range. Smoothhound however occurs in both areas (Personal observations).

In all samples, food occupied only small percentages of the available stomach volume.

5.3 b vii East Cape sample July 1973, results and discussion (See also Tables 33 and 34)

Results of feeding analyses are presented in Table 46.

Table 46: Feeding analyses of red cod stomach contents, East Cape, July 1973.

Food code	No. of times in sample (% occurrence)	Total points gained	Percentage of food	Percentage of available volume
1	6 (18.75%)	6	5.83	0.59
2	5 (15.62%)	15	14.56	1.47
3	1 (3.12%)	1	0.97	0.10
7	1 (3.12%)	2	1.94	0.20
34	1 (3.12%)	4	3.89	0.39
68b	9 (28.12%)	43	41.75	4.22
77	1 (3.12%)	1	0.97	0.10
115	8 (25.00%)	31	30.10	3.04
n = 51				

This sample was very small and contained only a small range of food. The quantity of food was also small, only 10.11% of the available stomach volume being occupied by food.

The most dominant food items were *Periclimenes (Harpilius) yaldwyni* (41.75%), and *Australomysis* sp. (30.10%). However, a large percentage of the food was unidentifiable (23.30%).

The only identifiable fish in this sample was the roughy *Paratrachichthys trailli* (3.89%). This was the only sample in which this species occurred.

5.3 b viii General discussion on the stomach contents analyses for the New Zealand region

From the foregoing analyses, it is clear that the red cod takes a wide range of marine organisms for food. There was variation in items taken from area to area, and variation in the relative quantities of items. These variations probably reflect changing availabilities of food items. Each area however can be characterized by the more important food items in the diet (Table 47).

Table 47: List of major items in the food of red cod from different areas around New Zealand (listed in order of abundance).

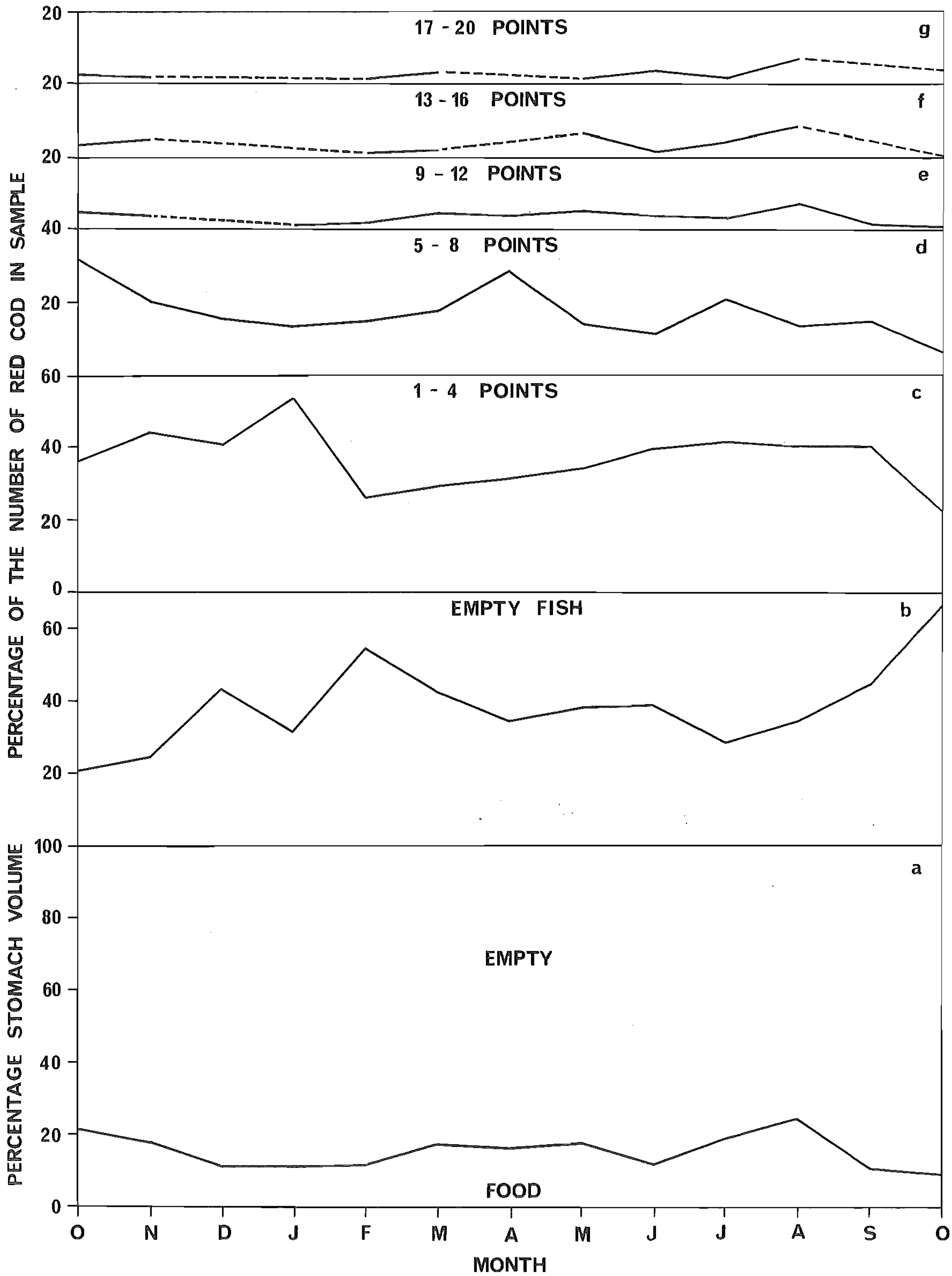
Area	Major food items
CANTERBURY	*Munida*, bluebonnet, opalfish, seaperch, tarakihi, swimming crabs, tunneling mud crab
OTAGO	policeman crab, *Munida*, *Ampelisca chiltoni*, *Squilla armata*, *Australomysis* sp., southern kingfish, *Pontophilus australis*, *Palaemon affinis*
FOVEAUX STRAIT	*Munida*
W.C.S.I.	hoki, whiting, lanternfish, seaperch, silverfish
W.C.N.I.	pilchards, *Nauticaris marionis*, tunneling mud crab, ahuru, *Callianassa filholi*, sole, sprat, leatherjacket
C.B.C.C.	*Ampelisca chiltoni*, *Munida*, *Allorchestes novizealandiae*, *Australomysis* sp., red gurnard, snapper
EAST CAPE	*Periclimenes (Harpilius) yaldwyni*, *Australomysis* sp., roughy

The balance of the food in each area was composed of a variable number of items which varied in composition and quantity from sample to sample.

In the feeding analyses for areas other than Canterbury, data are presented on the number of times food items were present (also converted to percent occurrences) in each monthly sample (See Tables

FIGURE 45

Stomach fullness in Canterbury area samples by month; a - percentages of stomach volume occupied by food, and empty; b - percentage of empty fish; c - percentage of fish allocated 1-4 stomach points; d - 5-8; e - 9-12; f - 13-16; and g - 17-20 points, percentages from b-g being of the total number of red cod in each monthly sample.



17 - 20 POINTS
g
13 - 16 POINTS
f
9 - 12 POINTS
e
5 - 8 POINTS
d
1 - 4 POINTS
c
EMPTY FISH
b
a
EMPTY
FOOD
PERCENTAGE OF THE NUMBER OF RED COD IN SAMPLE
PERCENTAGE STOMACH VOLUME
O N D J F M A M J J A S O
MONTH

35-46). This parameter was not discussed because it is similar to percentages of food by volume. The latter parameter was discussed. For details of similarities between these two parameters, see Section 5.3 b i (1).

Other points of stomach contents analyses are adequately discussed in the concluding discussions for each area.

5.3 c Stomach fullness by month by area

All monthly samples were analysed for stomach fullness following the allotment of stomach points by the method outlined in Section 5.2 d ii. Percentages of food by volume and percentages of empty volume resulted. Also computed were percentages of empty fish, and of fish allocated 1-4, 5-8, 9-12, 13-16, and 17-20 stomach points.

5.3 c i Canterbury stomach fullness analyses (Fig. 45)

The red cod in the samples from this area contained only small quantities of food. These ranged from 24.13% food in relation to the available stomach volume (August 1972 sample), down to 8.62% for the October 1972 sample. The mean food percentage for all samples was 15.39%. For a fish which has been observed to consume large quantities of food (See Graham, 1953, pp. 169-170), the above result would appear to be anomalous.

It is possible that the method of points allocation erred by being too conservative. This would have reduced the total number of points gained by the samples and hence the percentage of food. This could have resulted from the setting of too high a limit for a full stomach. In all samples, full stomachs were rare. It was noticeable that the red cod stomach is remarkably distensible. This feature, which might be considered propitious for the opportunistic aspect of red cod feeding (See Section 5.3 b i (1)), could have led me to adjudge an "ultra-full stomach", which utilized completely the stomach's distensibility, an "ordinary full stomach". Ultra-full stomachs were quite rare and probably resulted from feeding situations where a temporarily very abundant food source was available. On the other hand, ordinary full stomachs were much more common, and this level of fullness during times of normal feeding probably represented a full stomach (NB: The above reasoning also applies in the following discussions on stomach fullness in the other areas studied).

Notwithstanding the above reasoning, feeding levels were low. There were large numbers of empty or near empty fish in most samples. It is possible that there was a shortage of food for cod during the period of the study. There was a considerable decline in red cod catches throughout the New Zealand region at this time (See Section 3). This decline may have been linked with a food shortage.

There were no marked seasonal fluctuations in the pattern of feeding in this area.

5.3 c ii Otago stomach fullness analyses (Table 48)

Table 48: Percentages of food by volume and percentages of empty volume of red cod stomachs in each monthly sample, Otago. Also presented are percentages of the total number of fish in each sample with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories					
				E	1-4	5-8	9-12	13-16	17-20
May 71	39	15.90	84.10	33.33	41.03	20.51	-	-	5.13
Nov 71	128	28.48	71.52	12.50	39.06	24.22	12.50	4.69	7.03
Feb 72	91	22.80	77.20	3.30	56.04	31.87	7.69	1.10	-

All samples from this area contained only small quantities of food. These ranged from 28.48% food in relation to the available stomach volume (November 1971 sample) down to 15.90% for the May 1971 sample. The mean food percentage for all three samples was 22.39%, which was somewhat higher than the corresponding percentage for all Canterbury samples.

Over half the fish in all Otago samples had either empty stomachs, or stomachs containing only small quantities of food.

There were too few samples to show seasonal feeding patterns.

5.3 c iii Foveaux Strait stomach fullness analyses (Table 49)

Almost all the fish in this sample were less than half full, while 88.16% of the available stomach volume went unutilized. However, 8.53% of the fish contained some food. This sample contained considerably less food than the corresponding Canterbury and Otago samples.

Table 49: Percentage of food by volume and percentage empty volume of red cod stomachs, Foveaux Strait. Also presented are percentages of the total number of fish with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories E	1-4	5-8	9-12	13-16	17-20
Nov 71	122	11.84	88.16	11.48	76.23	11.48	0.82	-	-

5.3 c iv W.C.S.I. stomach fullness analyses (Table 50)

Table 50: Percentage of food by volume and percentage empty volume of red cod stomachs, W.C.S.I. Also presented are percentages of the total number of fish with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories E	1-4	5-8	9-12	13-16	17-20
Mar 72	210	25.29	74.71	51.90	13.81	9.52	2.86	8.57	13.33

Just over one quarter of the available stomach volume was occupied by food in this sample. This was considerably more than for the corresponding Canterbury sample (16.91%). Almost half the fish contained food, and there was a relatively high percentage of fish with full or almost full stomachs. Other details are presented in Table 50.

5.3 c v W.C.N.I. stomach fullness analyses (Table 51)

Table 51: Percentages of food by volume and percentages of empty volume of red cod stomachs in each monthly sample, W.C.N.I. Also presented are percentages of the total number of fish in each sample with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories E	1-4	5-8	9-12	13-16	17-20
Sep 71	95	9.00	91.00	35.79	53.68	9.47	1.05	-	-
Nov 71	48	10.00	90.00	27.08	62.50	6.25	4.17	-	-
Oct 73	60	12.50	87.50	55.00	31.67	3.33	3.33	3.33	3.33

The quantities of food in all three samples from this area were very small. Over 80% of the fish in all samples were either empty, or contained only a little food. Other details are presented in Table 51.

5.3 c vi C.B.C.C. stomach fullness analyses (Table 52)

Table 52: Percentages of food by volume and percentages of empty volume of red cod stomachs in each monthly sample, C.B.C.C. Also presented are percentages of the total number of fish in each sample with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories E	1-4	5-8	9-12	13-16	17-20
Feb 72	19	3.16	96.84	63.16	36.84	-	-	-	-
May 72	165	9.70	90.30	50.91	32.73	13.94	1.82	-	0.61
Sep 72	35	11.71	88.29	45.71	37.14	14.29	-	-	2.86

As was found for other areas, the red cod from this area contained little food. The February 1972 sample contained the least food of any of the samples analysed during this study (3.16% by volume). The May and September samples contained more food.

As for the W.C.N.I. samples, over 80% of the fish in all samples were either empty, or contained only a little food. For the February sample, this was the case for all fish.

5.3 c vii East Cape stomach fullness analyses (Table 53)

Table 53: Percentage of food by volume and percentage empty volume of red cod stomachs, East Cape. Also presented are percentages of the total number of fish with empty stomachs, or allocated 1-4, 5-8, 9-12, 13-16, or 17-20 stomach points.

Month and year	No. of fish in sample	% food	% empty (E)	Percentage of number of red cod in points categories E	1-4	5-8	9-12	13-16	17-20
Jul 73	51	10.10	89.90	41.18	37.25	21.57	-	-	-

This sample was similar to those from other areas in containing little food (10.10% by volume). All fish had stomachs which were less than half full, 41.18% being empty.

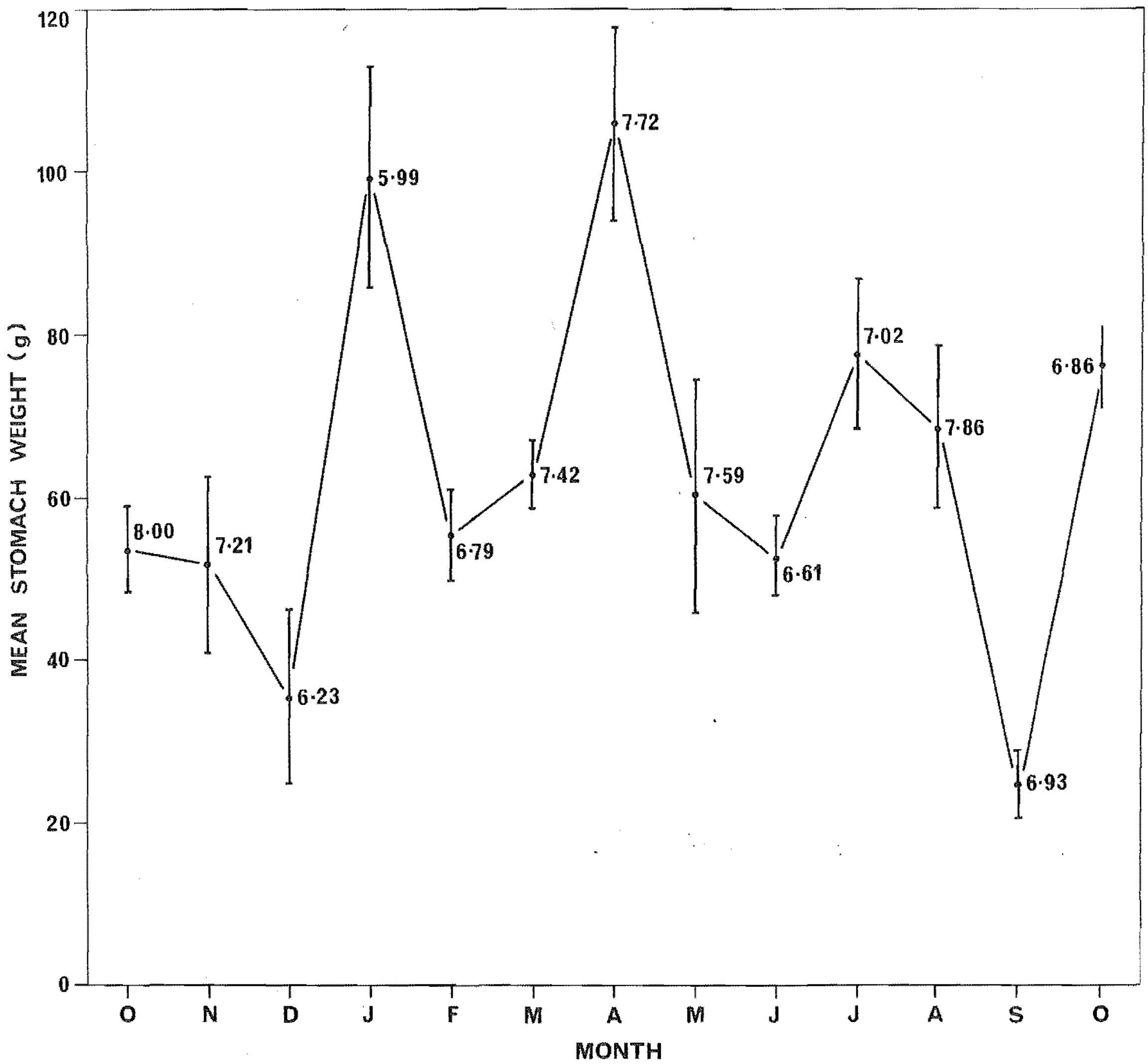
FIGURE 46

Mean stomach weights for Canterbury samples, October 1971 - October 1972. The 95% confidence limits are shown by vertical bars. The values in the figure represent stomach fullness indices. Other relevant statistics for data in Figure 46 were:

Month	n	S.E.	S.D.	g^1	g^2	K-S DMAX
October 1971	210	2.7655	40.0766	0.6708	0.2731	0.0904
November	102	5.4697	55.2411	1.0662	-0.0257	0.1927**
December	44	5.3806	35.6911	2.9252	11.6766	0.2331*
January 1972	88	6.7312	63.2096	-0.2340	-0.7290	0.1650*
February	156	2.8173	35.1884	0.5349	-0.2413	0.0570
March	248	2.0752	32.6797	2.6629	13.2111	0.1296**
April	107	5.9152	61.1878	0.8175	0.9553	0.0891
May	175	7.2396	95.7706	1.9316	3.6061	0.2994**
June	330	2.4828	45.1025	1.9163	4.6621	0.1696**
July	210	4.6768	67.7737	1.1645	2.2398	0.1224**
August	143	5.0263	60.1053	1.7826	7.1041	0.1233*
September	119	2.0175	22.0086	1.8867	5.1062	0.1325*
October	362	2.5477	48.4737	1.1067	2.3359	0.0891**

* significant at 5% level; ** significant at 1% level.

NB: For explanations of the above statistics, see Sokal and Rohlf (1969, pp. 112-118, 571-575).


MEAN STOMACH WEIGHT (g)
120
100
80
60
40
20
0
8·00
7·21
6·23
5·99
6·79
7·42
7·72
7·59
6·61
7·02
7·86
6·93
6·86
O
N
D
J
F
M
A
M
J
J
A
S
O
MONTH

5.3 c viii General discussion on stomach fullness analyses

All samples taken for stomach fullness analyses contained small quantities of food. The largest amount of food occurred in the Otago sample for November 1971 (28.48% by volume), and the smallest, in the C.B.C.C. sample for February 1972 (3.16%). Most fish were less than half full of food, and almost 40% contained no food at all. In only three samples were there substantial numbers of fish with stomachs which were more than half full. These were the Canterbury August sample (22.37% of the fish), the W.C.S.I. sample (24.76%), and the Otago November sample (24.22%).

It is thought that the quantities of food taken in this study were underestimated, especially with regard to the stomachs containing larger quantities of food. However, it is clear that the amount of food taken in all samples was low.

5.3 d Further feeding analyses (See Section 5.2 e)

5.3 d i Canterbury analyses

5.3 d i (1) Mean stomach weights and stomach fullness indices by month

Results of these analyses are presented in Figure 46.

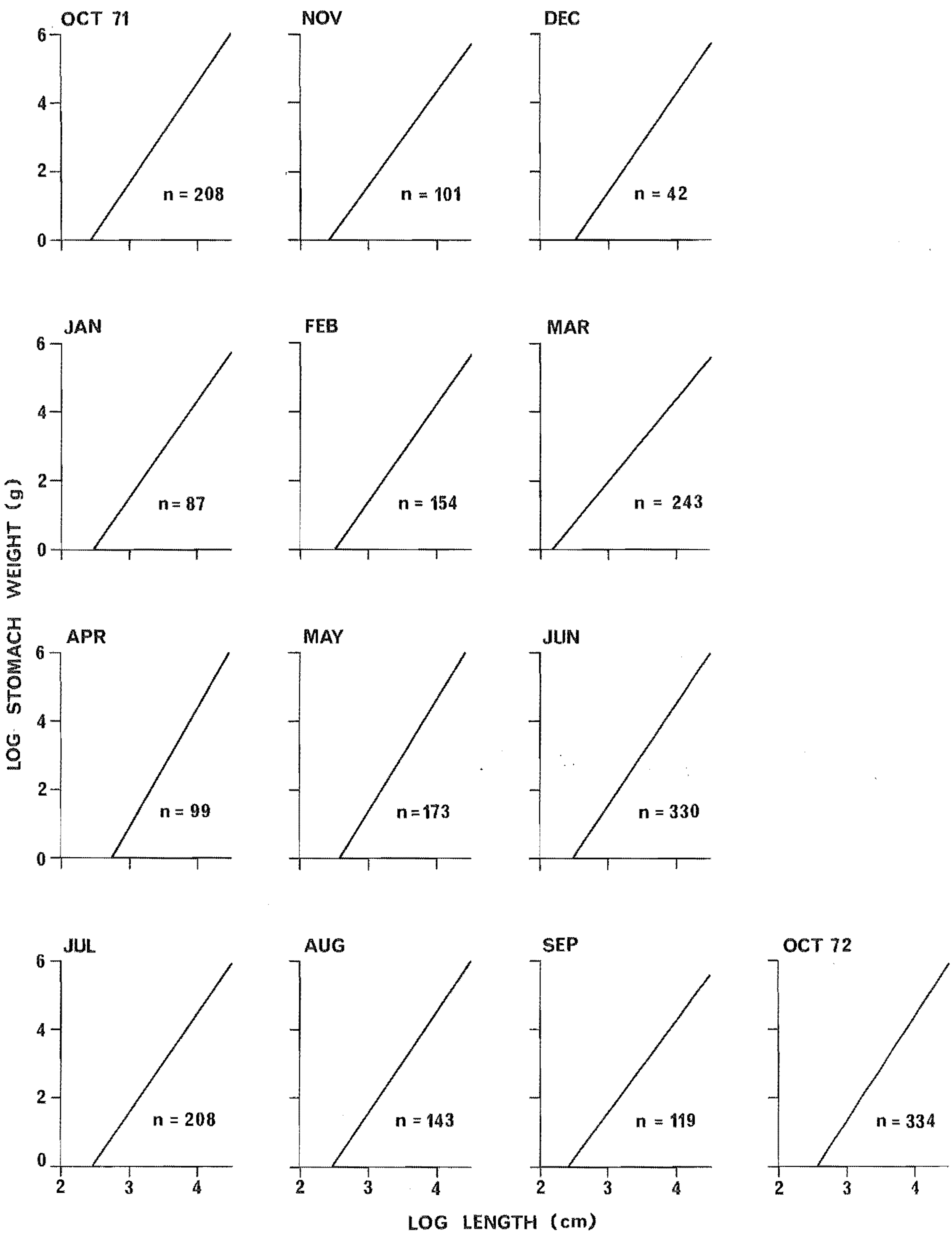
There was considerable variation in monthly mean stomach weights in these samples. Some of this variation was probably due to variations in the quantities of food taken. It is likely though that most of it was due to the monthly differences in proportions of the different size classes of fish in the samples. For example, the December 1971 and September 1972 samples were predominantly made up of smaller fish, and both samples had very low mean stomach weights.

Stomach fullness indices, or mean monthly stomach weights as percentages of mean fish gutted weights, gave a better indication of variation in stomach weight by month. The highest values for this measurement were found in the October 1971 and August 1972 samples, and the lowest in the December 1971 and January 1972 samples. These values can be correlated with the relatively high and low food volume percentages which were recorded for these samples (See Figs 34, 36a, 36b, 43a and 45). Similar correlations can be made for all other samples.

FIGURE 47

Log-log plots of red cod total length-stomach weight relationships for Canterbury samples October 1971 - October 1972. The regression equations are of the form Log Y (weight in g) = log a + b log X (length in cm). All r values were significant at the 1% level.

Month and year	Regression equation	r
October 1971	Y = -6.98496 + 2.88693 X	0.9578
November	Y = -6.83209 + 2.81379 X	0.9690
December	Y = -7.42051 + 2.94399 X	0.9646
January 1972	Y = -7.42777 + 2.94773 X	0.9860
February	Y = -7.13783 + 2.85091 X	0.8961
March	Y = 4.99011 + 2.33704 X	0.6700
April	Y = -9.00645 + 3.34462 X	0.9134
May	Y = -8.42969 + 3.27288 X	0.9908
June	Y = -7.25588 + 2.93718 X	0.9808
July	Y = 7.13584 + 2.91163 X	0.9808
August	Y = -7.12931 + 2.91025 X	0.9513
September	Y = -6.54639 + 2.70254 X	0.9642
October	Y = -7.87577 + 3.06722 X	0.9486


OCT 71
n = 208
NOV
n = 101
DEC
n = 42
JAN
n = 87
FEB
n = 154
MAR
n = 243
APR
n = 99
MAY
n = 173
JUN
n = 330
JUL
n = 208
AUG
n = 143
SEP
n = 119
OCT 72
n = 334
LOG STOMACH WEIGHT (g)
LOG LENGTH (cm)

5.3 d i (2) Red cod length-stomach weight regression

Results of these analyses are presented in Figure 47. Analysis of covariance was used to ascertain the relationship between a number of comparative combinations of the regressions presented in this figure (Table 54). For explanation of Analysis of Covariance testing, see Section 4.3 b i.

The variances of the regression in most combinations were non-homogeneous, as ascertained by Bartlett's test of homogeneity of variances. Of the twelve combinations in which variances were homogeneous, a common slope could be fitted to eight. Of these, four had a common intercept.

The sample combinations which were most similar were November - December 1971, December 1971 - January 1972, June - July 1972, and October 1971 - July 1972. The significance of these similarities is not clear. In terms of mean stomach weight and stomach fullness indices (Fig. 46), these samples were little correlated. It is possible that changes in the fish length composition of the samples, together with changes in monthly mean stomach weight, have combined to produce, by chance, similar regression relationships.

Comment

Presentation of data in the form of regressions and subsequent analyses of regression lines in the above manner are commonly carried out in relation to such things as fish length - body weight relationships (Sections 4.2 c, 4.3 b, Figs 31 and 32), and fish length - gonad weight relationships (Sections 6.2 b, 6.3 b). In these relationships, the mathematical relationship between the variables is ascertained and seasonal variations measured. It was thought such analyses might have been appropriate to the fish length - stomach weight relationship. However, the inherent variation in the samples negated any useful findings arising from these analyses.

5.3 d ii Other areas analyses

5.3 d ii (1) Mean stomach weights and stomach fullness indices by month (Table 55)

In the table, X refers to fish length, Y to stomach weight. The lengths are included to show that the size range of fish in the

Table 54: Analysis of covariance testing of comparative combinations of red cod total length-stomach weight regressions, Canterbury samples. (Key to numbers in comparative combinations: 1-13 = October 1971 - October 1972.) For all testing, $P < 0.01$.

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficient for combinations
1 - 13	x		x		x		
1 + 2	√	0.23119	√	0.60030	x		
1 + 3	x		x		x		
1 + 4	x		x		x		
1 + 5	x		x		x		
1 + 4	x		x		x		
1 + 5	x		x		x		
1 + 6	x		x		x		
1 + 7	x		x		x		
1 + 8	x		x		x		
1 + 9	x		x		x		
1 + 10	x		x		x		
1 + 11	x		x		x		
1 + 12	x		x		x		
2 + 3	√	6.33250	√	0.52090	√	4.57411	$Y = -6.93374 + 2.83202 X$
3 + 4	√	0.65140	√	0.72205	√	0.17431	$Y = -7.43637 + 2.94948 X$

Table 54: Continued

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficient for combinations
4 + 5	x		x		x		
5 + 6	x		x		x		
6 + 7	x		x		x		
7 + 8	x		x		x		
8 + 9	√	0.65510	x		x		
9 + 10	√	0.17700	√	0.12041	√	0.84082	Y = -7.17830 + 2.91890 X
10 + 11	x		x		x		
11 + 12	x		x		x		
12 + 13	√	0.12559	x		x		
1 + 3	x		x		x		
1 + 4	x		x		x		
1 + 5	√	2.39417	√	0.83128	x		
1 + 6	√	2.04631	x		x		
1 + 7	x		x		x		
1 + 8	√	4.15587	x		x		
1 + 9	√	2.35509	√	0,3437	x		
1 + 10	√	3.07415	√	0.11956	√	3.50745	Y = -7.05756 + 2.89860 X

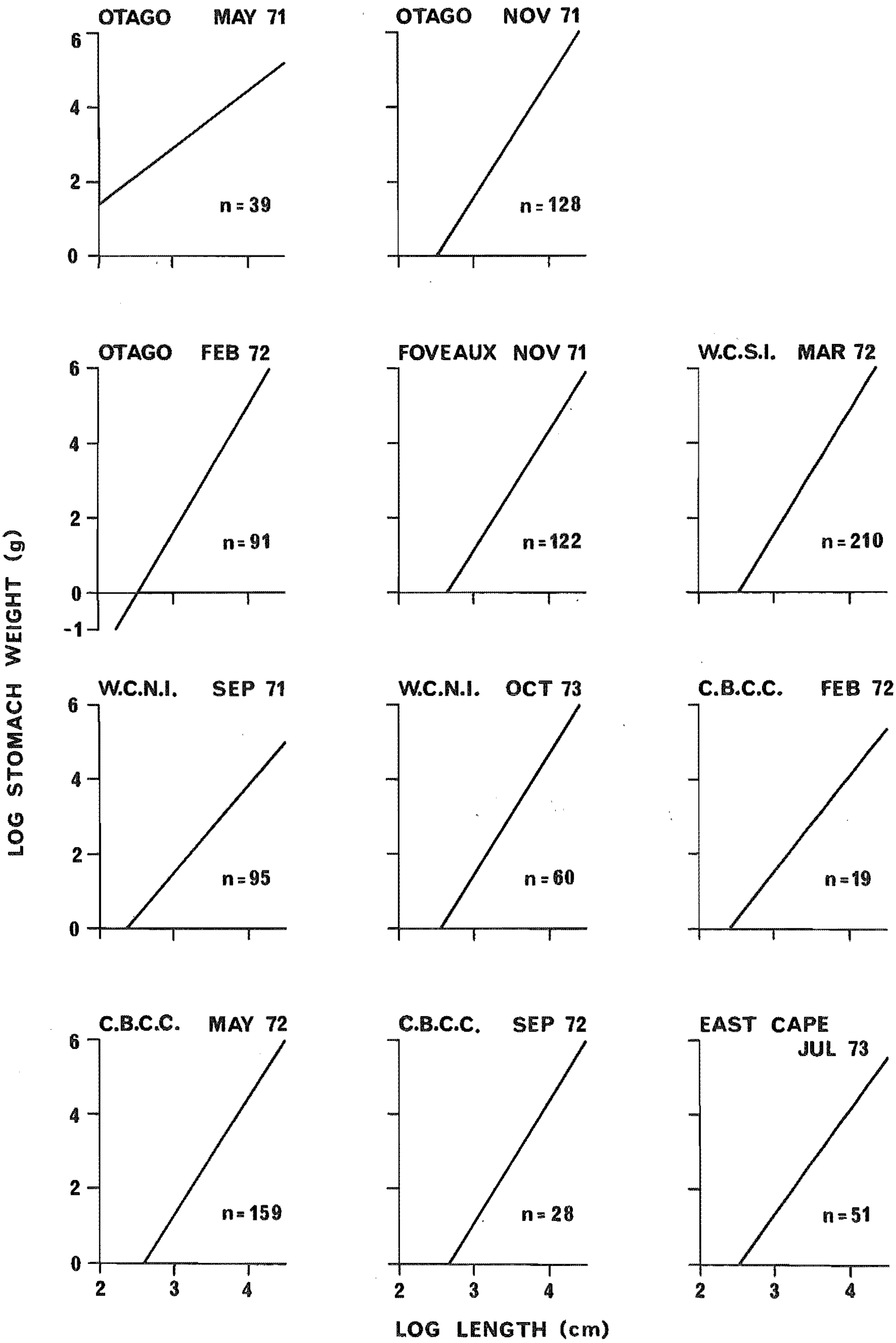
Table 54: Continued

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficient for combinations
1 + 11	x		x		x		
1 + 12	√	5.09903	√	3.63920	x		
1 + 13	x		x		x		
1,2,12,13	x		x		x		
3,4,5	x		x		x		
6,7,8	x		x		x		
9,10,11	x		x		x		

FIGURE 48

Log-log plots of red cod total length-stomach weight relationships for other areas studied. All r values were significant at the 1% level.

Area	Month and year	Regression equation	r
Otago	May 1971	Y = -1.9109 + 1.5812 X	0.4206
"	November 1971	Y = -7.8843 + 3.1452 X	0.9602
"	February 1972	Y = -8.5425 + 3.3892 X	0.9312
Foveaux Strait	November 1971	Y = -7.9194 + 3.0555 X	0.6950
W.C.S.I.	March 1972	Y = -8.4209 + 3.3256 X	0.8447
W.C.N.I.	September 1971	Y = -520183 + 2.2539 X	0.8595
"	October 1973	Y = -8.0179 + 3.1542 X	0.9463
C.B.C.C.	February 1972	Y = -4.6807 + 2.1996 X	0.6413
"	May 1972	Y = -8.0795 + 3.1319 X	0.9828
"	September 1972	Y = -9.2912 + 3.4190 X	0.9275
East Cape	July 1973	Y = -6.8406 + 2.7221 X	0.9775



OTAGO MAY 71
n = 39
OTAGO NOV 71
n = 128
OTAGO FEB 72
n = 91
FOVEAUX NOV 71
n = 122
W.C.S.I. MAR 72
n = 210
W.C.N.I. SEP 71
n = 95
W.C.N.I. OCT 73
n = 60
C.B.C.C. FEB 72
n = 19
C.B.C.C. MAY 72
n = 159
C.B.C.C. SEP 72
n = 28
EAST CAPE JUL 73
n = 51
LOG STOMACH WEIGHT (g)
LOG LENGTH (cm)
6
4
2
0
-1
2
3
4

Table 55: Mean stomach weights, stomach fullness indices, and other relevant statistics - other areas.

Area	Month and year	Mean X	Variance X	Mean Y	Variance Y	n	Stomach index (%)
OTAGO	May 1971	57.0935	1.0082	88.6433	1.1235	39	6.28076
"	Nov 1971	47.6847	1.1328	71.5796	3.8104	128	8.76154
"	Feb 1972	10.7274	1.0660	0.6062	2.3320	91	5.66154
FOVEAUX	Nov 1971	63.0785	1.0039	114.8664	1.0782	122	6.77568
W.C.S.I.	Mar 1972	26.5455	1.0658	11.9790	2.6844	210	7.69003
W.C.N.I.	Sep 1971	24.0761	1.0990	7.1130	1.9146	95	6.52534
"	Oct 1973	32.1149	1.0899	18.6363	2.6023	60	6.09874
C.B.C.C.	Feb 1972	61.1036	1.0026	78.6816	1.0314	19	4.33742
"	May 1972	19.4001	1.3586	3.3446	22.4603	159	5.46911
"	Sep 1972	52.1842	1.0467	68.7433	1.8588	28	6.48213
EAST CAPE	Jul 1973	20.6983	1.1312	4.1860	2.6015	51	5.37005

samples varied considerably. As was found for the Canterbury samples, such variation directly affected mean stomach weights.

However, stomach fullness indices, which could better be used to demonstrate changes in stomach weight from sample to sample, were computed. The lowest value for this statistic was that for the February C.B.C.C. sample. This can be correlated with the low volume of food which occurred in this sample (3.19%, see Table 43). Conversely, the highest value was for the November Otago sample. This can be correlated with the relatively high food volume of this sample (28.48%, see Table 36). Similar correlations can be made for the other samples. There are also correlations between stomach fullness indices and stomach fullness percentages as presented in Sections 5.3 c ii-viii.

5.3 d ii (2) Red cod length-stomach weight regressions

Monthly regressions by area are presented in Figure 48. Analysis of covariance was used to compare regression lines. Comparisons were also made between the regression lines in Figures 47 and 48. Comparisons were of the form as set down in Section 5.3 d i (2). All comparisons are presented in Table 56. In this table, a number

Table 56: Analysis of covariance testing of comparative combinations of red cod total length - stomach weight regressions, other area samples, as well as Canterbury samples. For all testing, $P < 0.01$.

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficients for combination
14 + 15	√	0.10266	x		x		
15 + 16	√	0.14413	√	2.30711	√	0.22909	Y = -8.09549 + 3.20017 X
14 + 16	x		x		x		
14,15,16	√	0.35346	√	4.93388	x		
19 + 20	√	4.72165	x		x		
21 + 22	x		x		x		
21 + 23	x		x		x		
22 + 23	√	0.42583	√	0.92454	√	1.07386	Y = -8.02875 + 3.11191 X
21,22,23	x		x		x		
8 + 14	√	0.49604	x		x		
2 + 15	√	0.47840	x		x		
5 + 16	√	2.71454	x		x		
2,5,8,14-16	√	12.98784	x		x		
2 + 17	x		x		x		
6 + 18	x		x		x		
10 + 24	x		x		x		
15 + 17	x		x		x		

Table 56: Continued

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficients for combination
1 + 20	√	0.87921	√	2.64537	√	3.83068	Y = -7.20025 + 2.94026 X
12 + 19	x		x		x		
13 + 20	√	0.84403	√	0.37020	x		
1,13,20	x		x		x		
5 + 21	x		x		x		
8 + 22	√	1.05911	√	6.03203	√	5.56742	Y = -8.34259 + 3.23454 X
12 + 23	√	0.11757	x		x		
16 + 21	x		x		x		
14 + 22	√	0.14721	x		x		
19 + 23	√	3.96407	x		x		

code is used to refer to the different area-month combinations which were tested. Numbers 1-13 refer to Canterbury samples October 1971 - October 1972; 14-16 to Otago May, November and February samples, 17 to the Foveaux Strait sample; 18 to the W.C.S.I. sample; 19-20 to the September and October W.C.N.I. samples; 21-23 to the February, May and September C.B.C.C. samples; and 24 to the East Cape sample.

Of the 27 combinations tested, variances were homogeneous in 15. To 6 of these, a common slope could be fitted, and of these 6, a common intercept could be applied to 4.

The regressions which were most similar were the November and February Otago samples, the May and September C.B.C.C. samples, the October 1971 Canterbury - October 1973 W.C.N.I. combination, and the May samples from Canterbury and C.B.C.C.

As for the Canterbury sample comparisons (5.3 d i (2)), the significance of the above similarities is not clear. As can be seen in Table 57, there were few corresponding similarities between the samples concerned in terms of food volume percentages or stomach fullness indices. The sample sizes also varied considerably, as did the size composition of the samples (See Table 55).

Table 57: Volumes of food and stomach indices for the most similar regression combinations listed in Table 56.

Comparative combination		n		Volume of food (%)		Stomach index (%)	
Area, Month 1	Area, Month 2	1	2	1	2	1	2
Otago, Nov 1971	Otago, Feb 1972	128	91	28.48	22.80	8.76	5.66
C.B.C.C., May 1972	C.B.C.C., Sep 1972	159	28	9.70	11.71	5.47	6.48
Canterbury, Oct 1971	W.C.N.I., Oct 1973	210	60	20.76	12.50	8.00	6.10
Canterbury, May 1972	C.B.C.C., May 1972	175	159	17.49	9.70	7.59	5.47

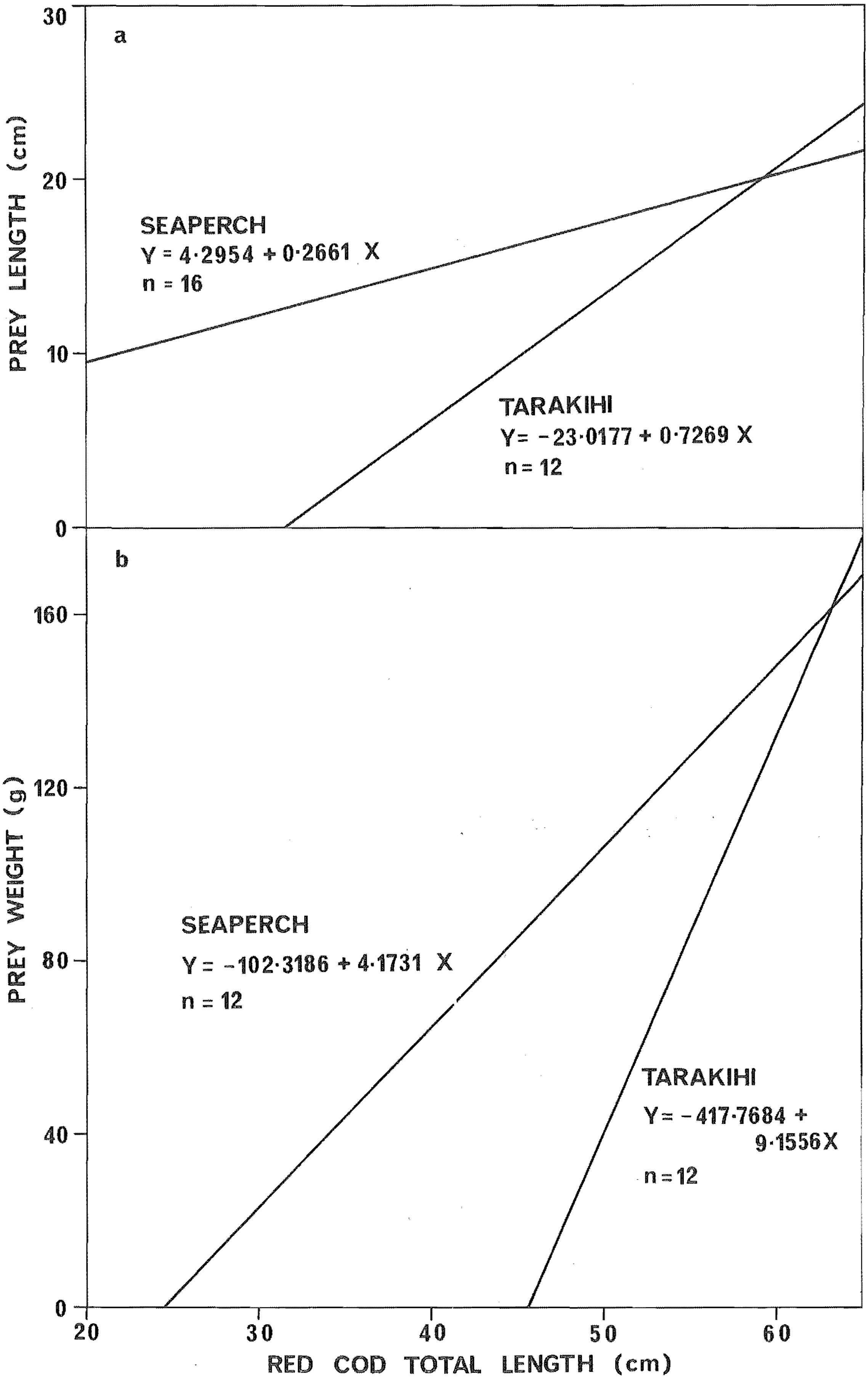
As for the Canterbury samples, it is possible that changes in fish length composition of the samples, together with changes in monthly mean stomach weight, combined to produce, by chance, similar regression relationships.

FIGURE 49a

Prey length - red cod length regressions for the prey species seaperch and tarakihi.

FIGURE 49b

Prey weight - red cod length regressions for the prey species seaperch and tarakihi.



a
SEAPERCH
Y = 4·2954 + 0·2661 X
n = 16
TARAKIHI
Y= −23·0177 + 0·7269 X
n= 12
b
SEAPERCH
Y = −102·3186 + 4·1731 X
n = 12
TARAKIHI
Y= −417·7684 + 9·1556X
n=12
PREY LENGTH (cm)
PREY WEIGHT (g)
RED COD TOTAL LENGTH (cm)
0
10
20
30
40
80
120
160
50
60

5.3 e Food size preferences

There have been many studies on food size preferences in fishes. For example, workers such as Swynnerton and Worthington (1940), Thomas (1962), Seaburg and Moyle (1964), and Keast (1965, 1970), looked at this aspect from the point of view of food and feeding studies of cohabiting fish species. Others, such as Smith (1947), and Maitland (1965), saw food size preferences as a function of prey size - predator ability to secure the prey species. Yet other workers (Dunn, 1954; Frost, 1954; Godfriaux, 1969; Kohler and Fitzgerald, 1969; Mann and Orr, 1969; Hellawell, 1971; Colman, 1972; and Ursin, 1973) studied variations in feeding with length of fish (predator).

Ursin's study, on the prey size preferences of two species of fish, was similar to that of this study. He saw the problem as being one of "... estimating the adequacy of one animal as prey to another...".

During stomach analyses of red cod from the Canterbury area in this study the prey species seaperch and tarakihi were often found intact and hardly affected by digestive processes. Their lengths and weights were recorded and these measurements were related to the lengths of the red cod from which they were taken (Figs. 49a and 49b).

Prey size increased with predator size. Inspection of the trawl contents from which the red cod were taken often showed a wide range of sizes of the two prey species. It would seem therefore that the bigger cod were actively selecting bigger prey. Kohler and Fitzgerald (1969) found a similar occurrence in their Northwest Atlantic cod samples.

In addition to the above, it was observed that small red cod (< 25 cm) feed mainly on small benthic invertebrates (See Section 5.3 b ii (3)).

5.4 Summary

1 An introduction to food and feeding of the red cod *Pseudophycis bacchus* is presented together with a review of other works. The aim of this study was to achieve "... a qualitative and quantitative analysis of the food and feeding of the red cod in New Zealand waters".

2 Monthly sample sizes by area are tabulated. From the Canterbury area, 2 294 fish were analysed. Other areas sampled with numbers

of red cod analysed in parentheses were Otago (258), Foveaux Strait (122), West Coast South Island (W.C.S.I.) (210), West Coast North Island (W.C.N.I.) (203), Cloudy Bay - Cape Campbell (C.B.C.C.) (219), and East Cape (51).

3 The method of dissection and aspects of the anatomy of the alimentary tract of red cod are discussed. Only the stomach was analysed.

4 The methods of assessment of stomach contents in fishes are reviewed, and the method used in this study outlined. A summary of other analyses which were carried out is also presented.

5 Food items which were present in the red cod diet are listed, and reference is made to items found by other workers. In this study, 134 food items were present.

6 Feeding analyses by individual food items by month by area were carried out. Statistics generated are:

(a) Percentage of food by volume, where food items are represented as percentages of the total quantity of food in each monthly sample,

(b) Percentages of available stomach volume, where food items are expressed as percentages of the available stomach volume in each monthly sample,

and (c) Percent occurrence, where food items are expressed as percentages of the number of times they occurred in each monthly sample.

For the Canterbury samples, two further analyses generated were the average number of points per occurrence in each sample of food items, and feeding diversity indices.

7 Red cod showed preferences for particular foods which differed in the different areas. These are listed.

8 Feeding analyses in terms of stomach fullness were also carried out. Because of the generally very low percentages of food present in relation to the available stomach volume, qualifications are placed upon the method of points allocation. The maximum volume utilized in the Canterbury samples was 24.13%,

Foveaux Strait (11.84%), W.C.S.I. (25.29%), W.C.N.I. (12.50%), C.B.C.C. (11.71%), and East Cape (10.10%). Almost 40% of all fish dissected were empty.

9 Feeding analyses by stomach weight were also carried out. Statistics generated were:

(a) Mean stomach weight by month by area,

(b) Stomach fullness indices (mean stomach weights as percentages of mean fish gutted weights) by month by area,

and (c) Regressions of log total length on log stomach weight by month by area.

Stomach fullness indices best indicated changes in feeding.

10 Food size preference studies were conducted. There was a positive relationship between size of predator (red cod) and size of prey (seaperch and tarakihi). The relationships are presented.

SECTION 6

REPRODUCTIVE BIOLOGY

6.1 Introduction

"Since the reproduction of organisms appears to be the organic activity toward which all life processes ultimately are directed, there is little need to dwell on the significant place it holds in biological studies." (Breder and Rosen, 1966). Concurring with this statement, the reproductive biology of the red cod was investigated during this study.

Little has been published on reproduction in red cod. Publications which occur may be summarised as follows: Beattie (1891) described the ovaries of female red cod; Thomson (1892, 1913) observed that red cod ova mature in August-September, ovaries ripen in October-November, and fish between two feet (61 cm) and three feet (91 cm) long are mature; Phillipps (1918, 1921, 1949) noted that while little is known of spawning habits, ova are ripe in October, and spawning occurs in mid-summer with the eggs probably floating on the surface of the sea; Graham (1939b), in observations on red cod in Otago waters, found that roes were ripe in July and August, and noted that mature adult fish move into offshore waters at this time, to spawn in about September. He deduced this from catching ten fish with ripe roes in 80 fathoms of water in September. The fish averaged 29 inches (74 cm) in length, 7.5 pounds (3.4 kg) in weight, and contained gonads weighing between 7.5 and 8.5 fluid ounces (0.21-0.24 kg). He dissected the gonads of three fish and calculated their fecundities, average egg diameters, and the size range of the oil globule of the eggs; Graham (1953) repeated his earlier findings with the additional note that after spawning, red cod became very thin on account of the enormous number of eggs produced compared with the size of the fish; Graham's findings were largely echoed by Parrott (1957), Doak (1972), and Watkinson and Smith (1972); and finally, various studies of the chemical constituents of the red cod liver were reported by Johnson (1921), Carter and Malcolm (1926), Malcolm (1926), Cunningham (1937), and Shorland (1937, 1948, 1950).

Personal communications from Russian (V.P. Shuntov, Pacific Research Institute for Sea Fisheries and Oceanography (TINRO), Vladivostock), and Japanese (T. Ogata, Japan Sea Regional Fisheries

Research Laboratory, Niigata, Japan; I. Ikeda, Far Seas Fisheries Research Laboratory, Shimizu, Japan) researchers working in New Zealand waters provide additional information on the reproductive biology of the red cod.

Shuntov found that red cod reproduce in the summer months and that shortly thereafter, juveniles can be found on the continental shelf in depths ranging from 300-750 m (Moreland (in Knox, 1957) found a similar juvenile red cod distribution on the Chatham Rise). These findings, together with a similar finding by Ogata ("... the juveniles were found in the deep sea, 250-755 meters...") seems to provide circumstantial evidence for Graham's (1953) contention that the red cod spawns in deep water. Ogata supported this view.

Ikeda made observations on the condition of red cod gonads in spring and summer at various stations around New Zealand. In Canterbury waters, 27% of his samples contained recovering spent gonads in September, 14% in October, and none in November. On the Auckland Island Shelf (Fig. 3), 17% were still in the recovering spent condition in January, and on the Bounty Platform (Fig. 3), 57% were in this condition in February. As recovering spent gonads are indicative of recent spawning, Ikeda's findings show that spawning in red cod occurs from early spring to late summer with increasing latitude.

During this study, the reproductive biology of the red cod from seven areas around New Zealand (For details of areas, see Section 1) was investigated (For details of sample sizes, see Tables 27-33).

It was hoped that the time and duration of the spawning season could be ascertained. To this end, the following statistics were calculated, by area, by month:

(1) Mean gonad weights,

(2) Maturity coefficients i.e. Mean gonad weights as percentages of mean gutted body weights, and

(3) Percentages of gonads in different stages of maturity.

In addition, fecundity and the distribution of egg sizes of the ovaries were measured. Plankton samples were taken in the hope that eggs of red cod could be collected from the surface waters to indicate not only time and duration of spawning, but also place.

It was also hoped that information on place of spawning could be gained from the pattern of catching

(i) ripe red cod at spawning time (As in Graham, 1953), and

(ii) juvenile fish after spawning (See Russian and Japanese pers. comms above).

During analyses, size at first maturity was noted as were sex ratios.

Seasonal variation in liver weight was monitored as a measure of "condition" here synonymized with fat reserves (See Carter and Malcolm, 1926, p. 649; Idler and Bitners, 1960; Stoddard, 1967, 1968; Bamford, 1970). It is well known that in many fishes, fat content undergoes large seasonal variations which are closely related to feeding and reproductive periods. And it has been pointed out that in gadoids, fat accumulates mainly in the liver (Nikolsky, 1963). It was hoped that seasonal variation in mean liver weight in red cod could be correlated with feeding and reproductive cycles.

6.2 Materials and Methods

6.2 a Gonad maturity stages

In studies on the reproductive biology of fishes, it is useful to record the state of maturity of fish examined. This yields information on such things as the proportion of the stock that is mature, size at first maturity, and the period of the year during which spawning occurs. As Karandikar and Palekar (1950) described it "A study of the developmental condition of the ovary has an intimate bearing on the breeding habits of fishes."

A number of schemes exist which have been used to classify maturity stages in many species of fishes, based on various features of the gonads (Bückmann, 1929; Kesteven, 1960; Nikolsky, 1963; Laevastu, 1965).

Gonads of red cod were classified into maturity stages using a scheme modified from the schemes of the workers cited above (Table 58). Ovarian classification was supplemented by information on egg sizes determined by microscopic examination.

Table 58: Classification scheme of maturity stages of red cod gonads.

STAGE	MALE	FEMALE
I	IMMATURE VIRGIN Testes long and thin, small, ribbony to tri-angular in cross section. Almost colour-less to white. Black connective tissue along inside margins and off anterior end. No milt.	IMMATURE VIRGIN Ovaries very small, short, rounded, tapering anteriorly. Partly trans-lucent to creamy white. Often with black connective tissue along inside margins. Eggs microscopic (0.025-0.10 mm diameter, most less than 0.07 mm), translucent.
II	MATURING VIRGIN Testes similar to Stage I, larger, tapered anteriorly. Considerably longer than Stage II ovaries. No milt.	MATURING VIRGIN Ovaries similar to Stage I, larger. Often partly pigmented. Unequal in length. Eggs microscopic (0.025-0.10 mm diameter, mode at 0.07 mm), translucent.
III	DEVELOPING Testes filling out, longer than Stage II, tapered anteriorly, tubular. Smooth tex-ture. No milt.	DEVELOPING Ovaries becoming swollen, lobular, round with some tapering anteriorly. Pink to creamy white. Network of blood vessels becoming apparent on surface of one ovary. Eggs micro-scopic to visible to the eye (0.03-0.20 mm diameter, mode at 0.10 mm), translucent to partly opaque.
IV	RIPENING Testes swollen, rounded. Slightly tapered anterior-ly. Creamy white. Smooth texture. No milt obvious with pressure or internal-ly.	RIPENING Ovaries swollen, lobular, rounded, large. Pinkish white. Blood vessels developing on both ovaries. Intern-ally highly laminated, laminations very obvious. Many eggs still micro-scopic, these translucent to slightly cloudy. Many bigger eggs (0.20-0.35 mm diameter, mode at 0.30 mm), partly to fully but lightly opaque.
V	GRAVID Testes very large, bulging. Creamy white. Velvet texture. Milt appears with pressure.	GRAVID Ovaries very large, sausage-shaped, bulging, heavily blood-vesseled. Pinkish. Internally, laminations masked by masses of mature eggs. Egg size range 0.05 to 0.60 mm diameter (modes at 0.25, 0.40 and 0.50 mm). From 0.13 mm, eggs partly opaque to densely opaque.

Table 58: Continued

STAGE	MALE	FEMALE
VI	SPAWNING Testes larger than in Stage V. Otherwise similar. Milt runs with slight pressure. One testis may be partly flaccid and becoming dull in colour.	SPAWNING Ovaries larger than in Stage V. Reddish pink. A few translucent eggs to 0.13 mm diameter. Most eggs range from 0.53-0.83 mm with some to 0.93 mm. Eggs densely opaque to 0.60 mm, clearing from the outside in the range 0.60-0.73 mm to become transparent, with a single yellow oil droplet (0.10-0.20 mm diameter). Eggs extruded with slight pressure. One ovary may be partly flaccid with pink colour fading.
VII	SPENT Testes flaccid, still large but shrinking. Grey white, dull, no more milt.	SPENT Ovaries flaccid, still large but shrinking. Most eggs spawned. The few remaining irregularly shaped eggs being resorbed.
VIII	RECOVERING SPENT Testes similar to Stage III but with a velvet texture. Often long and partly wrinkled. No milt.	RECOVERING SPENT Ovaries similar to Stage III but partly wrinkled. Rounded but hollow as internally, almost without sexual products of sufficient volume to occupy available gonad. New eggs developing, translucent (0.03-0.13 mm diameter). Occasional remains of eggs from recent spawning.

6.2 b Gonad weight, Maturity coefficient, M, and log-log regressions of gonad weight-fish length

Gonads of red cod, and fish minus their internal organs, were carefully blotted and weighed to 0.01 g. For the Canterbury samples, mean gonad weights by month were calculated for immature (0-19.9 cm total length - TL), maturing (20-52 cm TL), and mature (> 52 cm) fish. For samples from other areas, mean gonad weights were calculated for the whole samples by month.

Also calculated was the Maturity coefficient, M, that is, gonad weight expressed as a percentage of gutted body weight. A mean value of M was calculated for each sample by month by area.

Log-log regressions of gonad weight-fish length were also calculated for each sample by month by area.

As there were no obvious differences between male and female fish, all fish were considered together (This was the case for all other analyses in this section on reproductive biology).

6.2 c Condition

"The term "condition" is commonly used by the biologist to denote the general state of well-being of a fish (or other animal) or, more precisely, its physical capacity for survival and reproduction" (Cassie, 1957). It is a coefficient frequently used to measure variations in fish weight which are not associated with fish length (Jillett, 1968). In most studies, it is derived from the formula:

$$K = W \times 100/L^3$$

where K is condition factor, W is fish weight, and L, fish length (See Kesteven, 1947; Le Cren, 1951; Cassie, 1957, Jillett, 1968).

In this study, mean monthly liver weights were taken as measures of condition in red cod samples. The observation of fat deposits as an interpretation of condition is not unusual. For example, Halliday (1969a) measured the size of mesenteric fat deposits as an indicator of condition in the isospondylid *Argentina sphyraena*.

In the red cod, the liver, which is a large yellowish-brown structure surrounding the organs of the alimentary tract (Beattie, 1891), is the major site of food (fatty acid) storage (Carter and Malcolm, 1926). These workers found that the types of fatty acids present in the livers of summer-caught red cod were directly traceable to those of the major summer food species, whalefeed (*Munida gregaria*). They also found that the ratio of weight of liver to weight of flesh varies from 1:10 in summer fish to 1:15 in winter fish. They related the smaller winter livers to a lessened metabolism and poor food supply which caused these fish to utilise the reserves of food in their livers.

Livers were dissected from the Canterbury samples of red cod, blotted and weighed to 0.01 g. Mean monthly liver weights for immature, maturing, and mature (for length ranges, see 6.2 b) fish were calculated.

Log-log regressions of liver weight-fish length were also calculated.

6.2 d The ovary, seasonal variation in egg size, and fecundity

The ovary of the red cod is made up of numerous ovarian follicles embedded in connective tissue. New batches of ovarian follicles arise periodically from the germinal epithelium. At times of non-breeding, each follicle contains a small yolkless egg. Eggs of this type Bagenal (1966) called the "recruitment stock". Ranging in size from 0.025-0.10 mm in diameter, they could be found in red cod ovaries throughout the year. At each breeding season a quota of these yolkless eggs matured through progressive increase in size (to maximum 0.93 mm diameter), the addition of yolk, and maturation of the nucleus (See Hoar _in_ Brown, 1957, Ch. 7).

Seasonal variation in egg size was measured in all samples and relationships established between egg size ranges and gonad maturity stages (See Table 58).

The fecundity of fish is defined as the number of ripening eggs in the female prior to the next spawning period (Bagenal, 1968). In life history studies, the knowledge of the number of eggs produced is essential. Most fecundity estimates have been based on counts from small egg samples, adjusted to fecundity for individual fish by the ratio of weight or volume of total eggs to weight or volume of the sample. Descriptions of variations in these procedures are given by Raitt (1933), Simpson (1951), Bagenal (1957), Nagasaki (1958), Thompson (1959b), Kusakabe, Murakami, and Onbe (1962), Thomson (1962), Hodder (1963), Nikolsky (1963), Pitt (1964), and Hart (1967).

The fecundity of red cod from the different areas was estimated by counting eggs in a series of replicate subsamples. The only eggs counted were those greater than 0.13 mm in diameter.

After weighing the ovaries, they were stored in 5% formalin. At time of processing, five weighed subsamples of each ovary of a fish were taken and the contained eggs washed out into counting cells. The eggs were separated, not without difficulty, and spread evenly throughout the cells. In each cell, one-tenth of the grid squares were randomly chosen and the eggs in these counted. The number counted ranged from 300- 5 858. The number obtained was multiplied by ten to give the number of eggs in the cell.

The eggs were removed from the remaining portions of both ovaries and the ovarian skin and tissue weighed. This weight was subtracted from the original weight of the entire ovaries to obtain the weight of eggs in the ovaries.

Each cell count (ten per fish) was multiplied by the factor which converted the weight of the subsample to the weight of eggs in the ovaries. A mean value of these multiples was calculated and this represented the fecundity of each fish, or the individual fecundity.

However, the individual fecundity is not characteristic of the reproductive capacity of the population because the fecundity of the stock, or the population fecundity, is dependent not only on the individual fecundity, but also on the time and onset of sexual maturity, and on the periodicity and frequency of spawnings throughout the life of the individuals.

To obtain the population fecundity for the Canterbury red cod, a range of sizes of mature fish were analysed throughout the spawning season. The same seasonal choice of samples was not available for the other areas studied. In fact, spawning samples were not obtained from Otago and W.C.S.I. However, for Foveaux Strait, W.C.N.I., C.B.C.C. and East Cape, limited spawning samples were analysed.

In the analyses of Canterbury samples, fecundity was related to red cod length, gonad weight, gutted weight, and to the gutted weights of various size classes of mature fish. Gutted weight was chosen as that least susceptible to variation due to feeding and to gonad and liver weight cycles. This complex of analyses was carried out to determine which measurement was most suitable for estimating fecundity in red cod (See Bagenal, 1957, pp. 350-1).

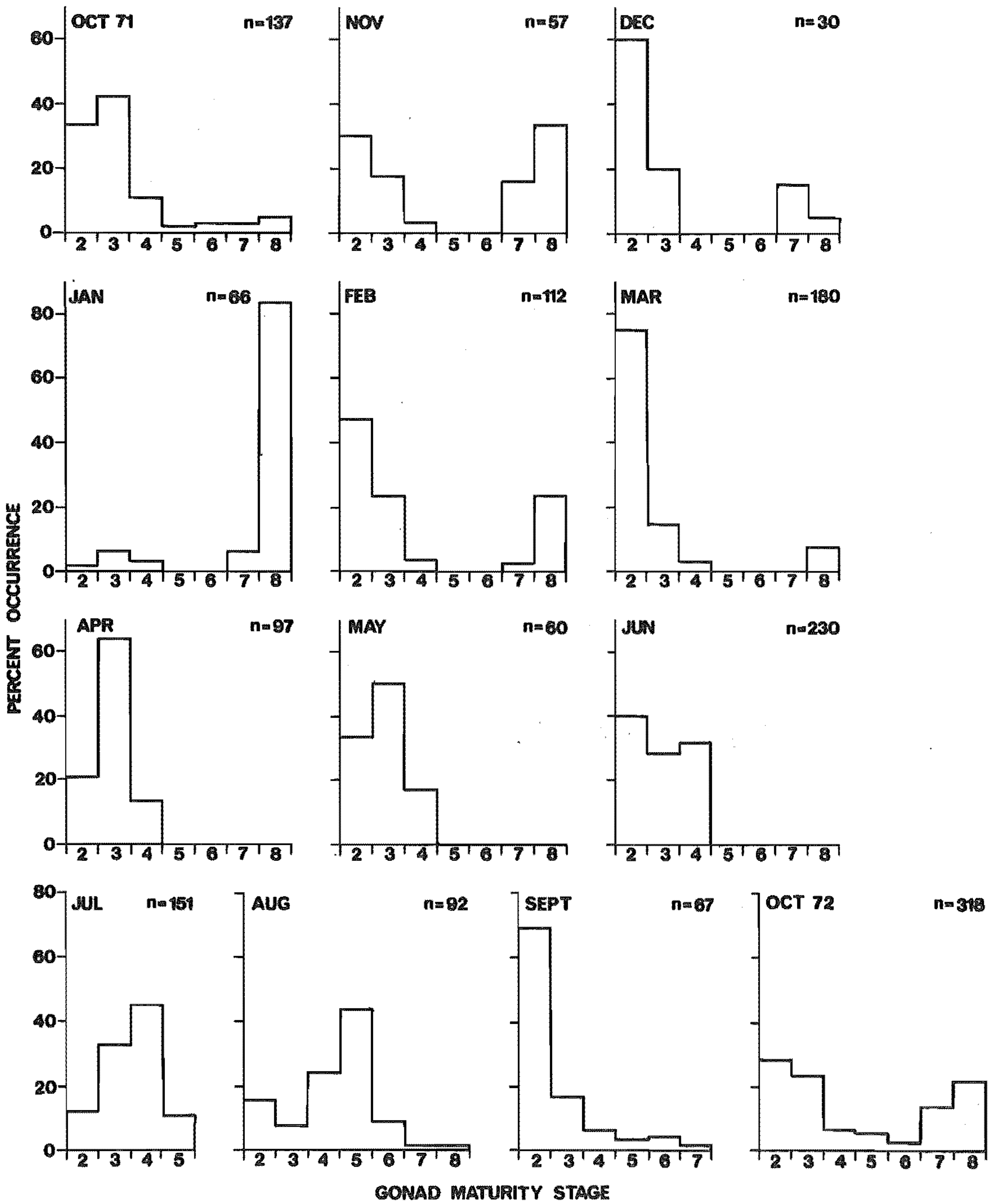
6.2 e Plankton samples

During the study, a half-metre diameter conical plankton net with a mesh of 0.22 mm aperture size (See Kilner, 1974 plate 4) was occasionally used to sample the plankton for red cod eggs and larvae. This net was towed in the surface waters for 30 to 90 minutes at speeds of three to four knots.

All plankton samples were sorted by Dr D.A. Robertson, Fisheries Research Division, Ministry of Agriculture and Fisheries, Wellington. At the time of my study, he was completing a fish egg and larval survey in New Zealand waters (See Robertson, 1973).

FIGURE 50

Percent occurrence of gonad maturity stages in Canterbury samples, October 1971 - October 1972.


OCT 71
n=137
NOV
n=57
DEC
n=30
JAN
n=66
FEB
n=112
MAR
n=180
APR
n=97
MAY
n=60
JUN
n=230
JUL
n=151
AUG
n=92
SEPT
n=67
OCT 72
n=318
PERCENT OCCURRENCE
GONAD MATURITY STAGE

6.3 Results and Discussion

6.3 a Seasonal variation in gonad maturity and size at first maturity

6.3 a i Canterbury samples October 1971 - October 1972

The percentages of red cod with gonads at various stages of maturity in each monthly sample are shown in Figure 50. Because there were no differences between male and female fish, all percentages were combined.

Fish with stage I gonads were not included in Figure 50. The numbers of immature virgin fish in each sample may be calculated by subtracting the numbers presented for each month in Figure 50 from the actual sample sizes as presented in Tables 27-33.

In all samples except that for January 1972, fish with stage II and III gonads were predominant reflecting the predominance of immature fish in the samples (those < 52.0 cm in length, see later in this section, also Fig. 26). As a result, the expected increase in fish with stages IV-VI gonads as the spawning season approached and commenced was masked.

Red cod in a gravid condition were first present in the July sample, and continued to occur through to October, with the largest percentage occurring in August.

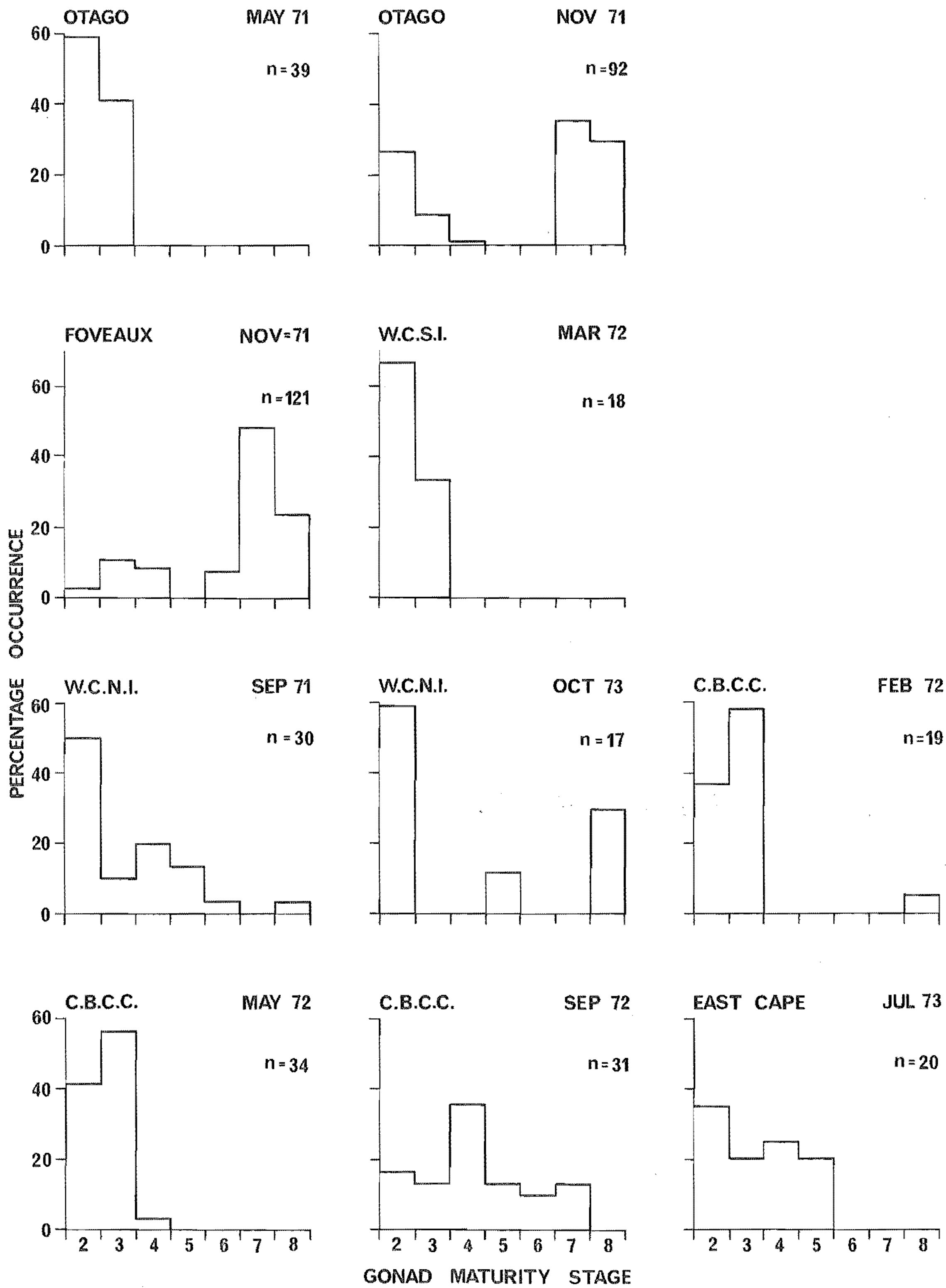
Spawning fish were caught in small numbers from August to October, with the largest percentage in August. There was great difficulty in obtaining spawning fish. This was because at spawning time, mature red cod moved into offshore waters (as determined by the pattern of catches of red cod in inshore and offshore waters) (See offshore sample stations for spawning months, Fig. 14). During these months of relatively unsettled weather, offshore waters were inadequately sampled.

From August to February, spent fish were caught, the largest percentages being taken in November and December. Recovering spent fish were found from August to April, with a peak percentage in January (83.5% of the sample). From November on, these spent fish could be caught in inshore waters, to which they returned after spawning.

To ascertain the size of red cod at first maturity, percentages of samples of immature and mature fish in the August to October

FIGURE 51

Percent occurrence of gonad maturity stages in samples from other areas May 1971 to July 1973.


OTAGO
MAY 71
n = 39
OTAGO
NOV 71
n = 92
FOVEAUX
NOV=71
n = 121
W.C.S.I.
MAR 72
n = 18
W.C.N.I.
SEP 71
n = 30
W.C.N.I.
OCT 73
n = 17
C.B.C.C.
FEB 72
n = 19
C.B.C.C.
MAY 72
n = 34
C.B.C.C.
SEP 72
n = 31
EAST CAPE
JUL 73
n = 20
PERCENTAGE OCCURRENCE
0
20
40
60
2
3
4
5
6
7
8
GONAD MATURITY STAGE

Canterbury samples were calculated (Table 59).

Table 59: Percentages of immature and mature red cod of different length ranges, Canterbury samples.

Red cod length range (cm)	Sample size	Percentage immature	Percentage mature
< 40.9	100	100.00	-
41.0 - 44.9	73	93.15	6.85
45.0 - 49.9	60	63.33	36.67
50.0 - 54.9	99	11.11	88.89
> 55.0	100	-	100.00

All fish < 40.9 cm in length were immature, while all over 55.0 cm were mature. Within these extremes, red cod attained maturity with most maturing between 50.0 and 54.9 cm. Because there was a considerable percentage of mature fish in the 45.0-49.9 cm category, the mid-point size at maturity was probably closer to 50.0 cm than 54.9 cm. For the purposes of this study therefore, the size at maturity in the Canterbury area can be taken as 52.0 cm in length.

6.3 a ii Other areas samples (Fig. 51)

The percentage of red cod with gonads at various stages of maturity in the monthly samples from Otago, Foveaux Strait, W.C.S.I., W.C.N.I., C.B.C.C., and East Cape are presented in Figure 51. As for the Canterbury samples, results for both male and female fish were combined and fish with stage I gonads excluded from consideration. Because of the small size of many of the samples, it should be realised that many of the following observations are limited.

6.3 a ii (1) Otago samples May and November 1971

Only the May and November 1971 samples could be analysed as the February 1972 sample contained only immature fish (See Fig. 27). Both samples were similar to the Canterbury samples from the same months. The May sample contained non-spawning fish while the November sample contained both non-spawning and spent fish. Referring to Graham's (1939b) work in Otago waters, further similarities can be found. He found gravid red cod in July and August, assumed that they spawned in

September in offshore waters, and found that sexual maturity in red cod was reached when they were about 20 inches (≃52 cm) in length, all features of the reproductive cycle of Canterbury cod. This cycle is therefore little different in these two areas.

6.3 a ii (2) Foveaux Strait sample November 1971

This sample, which was composed largely of mature fish (See Fig. 28), differed from the Canterbury and Otago November samples in that it contained spawning fish, and also a larger relative percentage of fish in a recently spent (stage VII) state. Bearing in mind the limitations of a single sample, a tentative conclusion that spawning was later in the Foveaux Strait area could be drawn.

Only three fish, in this sample were sexually immature. These measured 50.0, 51.0 and 54.0 cm in length. Because of the lack of smaller fish, deriving the size at first maturity was impossible. However, it was probably similar to that for Canterbury and Otago cod.

6.3 a ii (3) W.C.S.I. sample March 1972

Only 18 of the fish in this sample had gonads above stage I. All fish were sexually immature (with stage II and III gonads), which was consistent with the predominantly small fish in the sample (See Fig. 28), and the non-spawning period of the year (c.f. Canterbury March sample). Size at first maturity could not be ascertained.

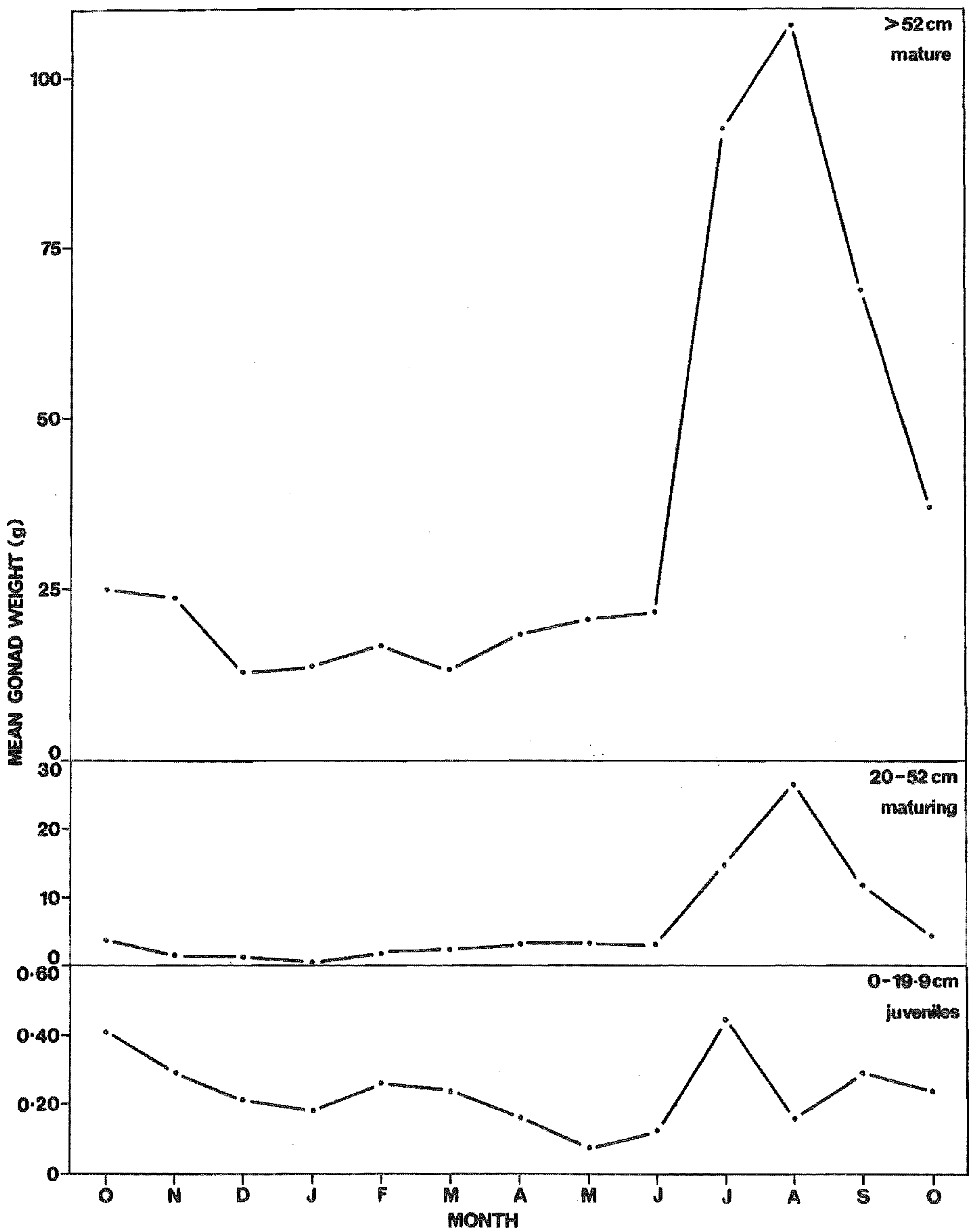
6.3 a ii (4) W.C.N.I. samples September 1971 and October 1973

Both samples contained large percentages of sexually immature fish. This was not surprising as the samples comprised mainly smaller fish (See Fig. 29). However, the gonads of the larger cod indicated that spawning was in progress. Gravid and recovering spent fish were present in both samples, while spawning fish were present in the September sample. This spawning period is comparable with that for the Canterbury cod.

However maturity was reached at a smaller size in W.C.N.I. cod. Although the largest fish in the September sample was 46 cm in length, and in the October sample, 50 cm, some 40% of the fish in each sample were sexually mature. In the September sample 70% of the fish between 36 cm and 46 cm were mature. One fish was mature at 36.3 cm.

FIGURE 52

Seasonal variation in mean gonad weight in Canterbury samples, October 1971 - October 1972.



>52 cm
mature
20–52 cm
maturing
0–19·9 cm
juveniles
MEAN GONAD WEIGHT (g)
100
75
50
25
0
30
20
10
0
0·60
0·40
0·20
0
O
N
D
J
F
M
A
M
J
J
A
S
O
MONTH

FIGURE 53

Red cod gonad weight - fish length relationships by month for Canterbury samples.

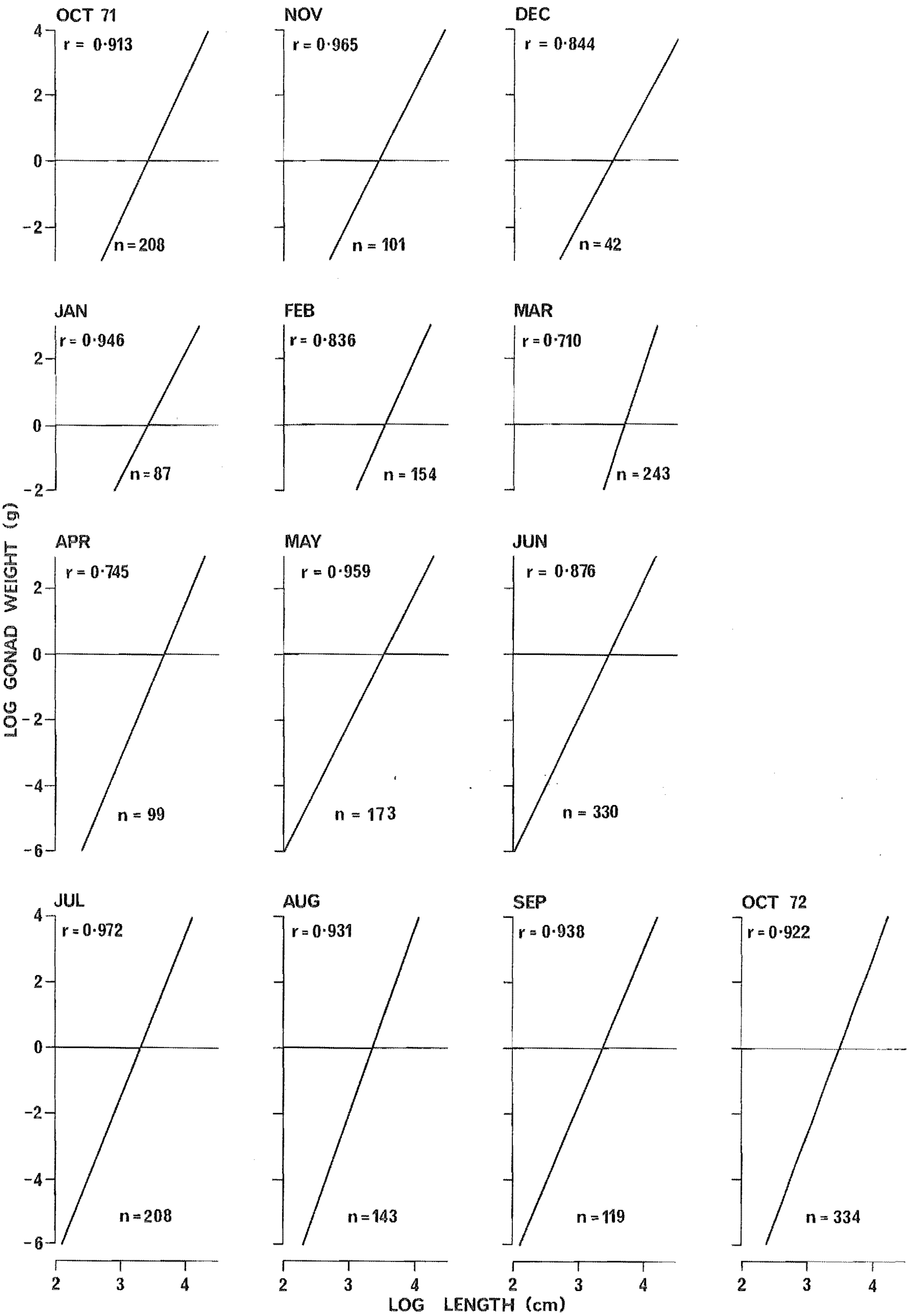
1971

October	log w	=	-14.825	+	4.334	log 1
November	"	=	-13.435	+	3.904	"
December	"	=	-13.101	+	3.738	"

1972

January	"	=	-13.321	+	3.879	"
February	"	=	-15.805	+	4.441	"
March	"	=	-23.388	+	6.309	"
April	"	=	-18.541	+	5.042	"
May	"	=	-14.225	+	4.043	"
June	"	=	-14.701	+	4.260	"
July	"	=	-16.433	+	4.963	"
August	"	=	-18.555	+	5.523	"
September	"	=	-15.591	+	4.626	"
October	"	=	-19.359	+	5.544	"

NB: All correlation coefficients (r) significant at the 1% level



OCT 71
r = 0·913
n = 208
NOV
r = 0·965
n = 101
DEC
r = 0·844
n = 42
JAN
r = 0·946
n = 87
FEB
r = 0·836
n = 154
MAR
r = 0·710
n = 243
APR
r = 0·745
n = 99
MAY
r = 0·959
n = 173
JUN
r = 0·876
n = 330
JUL
r = 0·972
n = 208
AUG
r = 0·931
n = 143
SEP
r = 0·938
n = 119
OCT 72
r = 0·922
n = 334
LOG GONAD WEIGHT (g)
LOG LENGTH (cm)

6.3 a ii (5) C.B.C.C. samples February, May and September 1972

Gonads in both the February and May samples were in non-spawning stages although a few recovering spent gonads were present in the February sample. In the September sample, all gonad stages except recovering spent were present. All samples were in fact very similar in gonad stage percentages to the corresponding Canterbury samples (Fig. 50). Additionally, first maturity was reached at about the same size in the two areas. It is probable that the reproductive cycle (as was also postulated for growth - see Section 4.3 a vi) is little different in Canterbury and C.B.C.C. red cod.

6.3 a ii (6) East Cape sample July 1973

The gonads in this sample were typical of pre-spawning fish. Some 25% were ripening and 20% gravid. No spawning stages were present. A similar distribution of gonad stages was found in the July Canterbury sample (Fig. 50), except that a larger proportion of the East Cape fish was gravid. Spawning was probably somewhat earlier in the East Cape area. East Cape cod certainly reached maturity at a smaller size (≃28 cm, c.f. 52 cm in Canterbury cod).

6.3 b Seasonal variation in gonad weight, maturity coefficient (M), and log-log regressions of the relationship gonad weight - fish length

6.3 b i Canterbury samples October 1971 - October 1972

Some 2 241 red cod were analysed in this section of the study. For numbers of fish analysed per month, see Figure 53.

Monthly mean gonad weights for juvenile (0-19.9 cm), maturing (20.0-52.0 cm), and mature (>52.0 cm) red cod are presented in Figure 52.

For juvenile fish, the mean gonad weight varied little throughout the year. The gonads represented about 0.30% of the gutted body weight. And for maturing and mature fish during the non-breeding period of the year, mean gonad weights also remained fairly constant. Gonads in maturing fish represented about 0.60% of the gutted body weight and in mature fish, about 0.70%.

However, with the approach and onset of the breeding season, there was a marked increase in mean gonad weight in maturing and mature fish. Between June and August, the increase for maturing fish was more than eight-fold, for mature fish, some five-fold.

The increase found in mean gonad weight in maturing fish is interesting. As these fish do not undergo spawning, such an outlay in body resources for sexual products would seem to be wasteful. It is possible though that this development constitutes a "dry-run" with regard to spawning. By going through all phases of the reproductive cycle the season before becoming mature, adult fish could conceivably be more successful when spawning. This would negate the need for the situation where young first-time spawning fish sometimes form only a reserve stock in spawning populations (See Nikolsky, 1963, p. 173).

I believe the increase for mature fish was an underestimate because there was undersampling of fully gravid larger fish. One red cod analysed (72.8 cm TL) had gonads which weighed 461.00 g, some 14.36% of the gutted body weight.

The monthly mean M values for this area are presented in Table 60.

Table 60: M values by month for Canterbury samples.

	Month	M(%)	Month	M(%)
1971	October	1.10	May	0.54
	November	0.94	June	0.57
	December	0.49	July	2.44
			August	2.93
1972	January	0.41	September	1.96
	February	0.49	October	1.22
	March	0.59		
	April	0.56		

M values varied in a similar manner to the mean gonad weights as expected. Because M was calculated for all fish in the samples, the values were lower than they would have been if they only represented reproductively active fish.

Seasonal variations in both mean gonad weights and M followed closely the pattern of seasonal progression of gonad maturity stages

(Section 6.3 a i). All these parameters adequately indicate the seasons of breeding and non-breeding for Canterbury red cod.

To describe the relationships between gonad weight and fish length, all data were transformed to logarithms (for reasons outlined by Sokal and Rohlf, 1969, pp. 382-384). These relationships for the Canterbury samples are presented in Figure 53.

To establish the degrees of relationship between the regression lines in this figure, the equations of 13 pairs of regressions were compared using analysis of covariance (For details of the method of testing, see Section 4.3 b i). Results are presented in Table 61.

In 7 of the 13 combinations, the variances were homogeneous. For 4 of these combinations common slopes and intercepts could be fitted. For these, common regression coefficients were calculated.

The monthly pairs which were most similar were November and December 1971, December 1971 and January 1972, March and April 1972, and April and May 1972. These similarities are not surprising as these samples were comparable in both mean gonad weights by size groups (Fig. 52) and M values (Table 60). What is surprising is that the regressions for the October, February, and June samples were not similarly comparable. Mean gonad weights and M values were relatively constant for all samples from October 1971 - June 1972. It is probable that more uniformity was not manifested in the regressions because of variations in sample size and composition. These factors probably also account for the considerable lack of homogeneity between many of these samples from the same area (See Variances homogeneous column, Table 61).

6.3 b ii Other area samples

Information on area, month of sampling, sample size, mean and variance of fish length, mean and variance of gonad weight, and the mean maturity coefficient (M) of each sample are presented in Table 62. Some 1 002 red cod were analysed in this section of the study.

Table 61: Analysis of covariance testing of comparative combinations of red cod gonad weight - fish length regressions, Canterbury samples (Key to numbers in comparative combinations: 1-13 = October 1971 - October 1972; for all testing, P = < 0.01).

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficients for combination
1 + 2	x		x		x		
2 + 3	√	6.61684	√	0.25669	√	5.83815	Y = -13.43255 + 3.88184 X
3 + 4	√	0.99130	√	0.14104	√	4.87595	Y = -13.73817 + 3.96489 X
4 + 5	x		x		x		
5 + 6	√	0.59575	x		x		
6 + 7	√	2.72736	√	3.91134	√	3.59811	Y = -20.41108 + 5.52909 X
7 + 8	√	4.06114	√	3.60028	√	6.40271	Y = -13.9824 + 3.94698 X
8 + 9	x		x		x		
9 + 10	√	0.41080	x		x		
10 + 11	x		x		x		
11 + 12	x		x		x		
12 + 13	√	0.57393	x		x		
1 + 13	x		x		x		

Table 62: Mean fish length, gonad weight, and M values for samples from other areas by month.

Area	Date	n	Mean length (cm)	Variance	Mean gonad weight (g)	Variance	Mean maturity coefficient
OTAGO	May 71	39	57.1	1.00	7.73	1.59	0.65
"	Nov 71	128	47.7	1.13	5.81	37.98	1.05
"	Feb 72	91	10.7	1.07	0.02	1.72	0.22
FOVEAUX	Nov 71	122	63.1	1.00	31.43	1.44	2.15
W.C.S.I.	Mar 72	210	26.5	1.06	0.36	8.69	0.36
W.C.N.I.	Sep 71	95	24.1	1.09	0.39	27.27	1.07
"	Oct 73	60	32.1	1.09	0.65	34.60	0.36
C.B.C.C.	Feb 72	19	61.1	1.00	9.92	1.33	0.60
"	May 72	159	19.4	1.36	0.10	374.35	0.28
"	Sep 72	28	52.2	1.05	24.96	7.53	3.00
EAST CAPE	Jul 73	51	20.7	1.13	0.45	187.02	1.16

Because of the variation in mean fish length in these samples, little value can be placed upon the mean gonad weights as indicators of seasonality in the reproductive cycle. Ideally, mean gonad weights should have been related to specific fish length ranges as in the Canterbury samples (Fig. 52). However, because M values, which take into account variations in size composition of the samples, were considered sufficient to indicate seasonality in the somewhat "patchy" samples from these other areas, further analyses on mean gonad weights were not attempted.

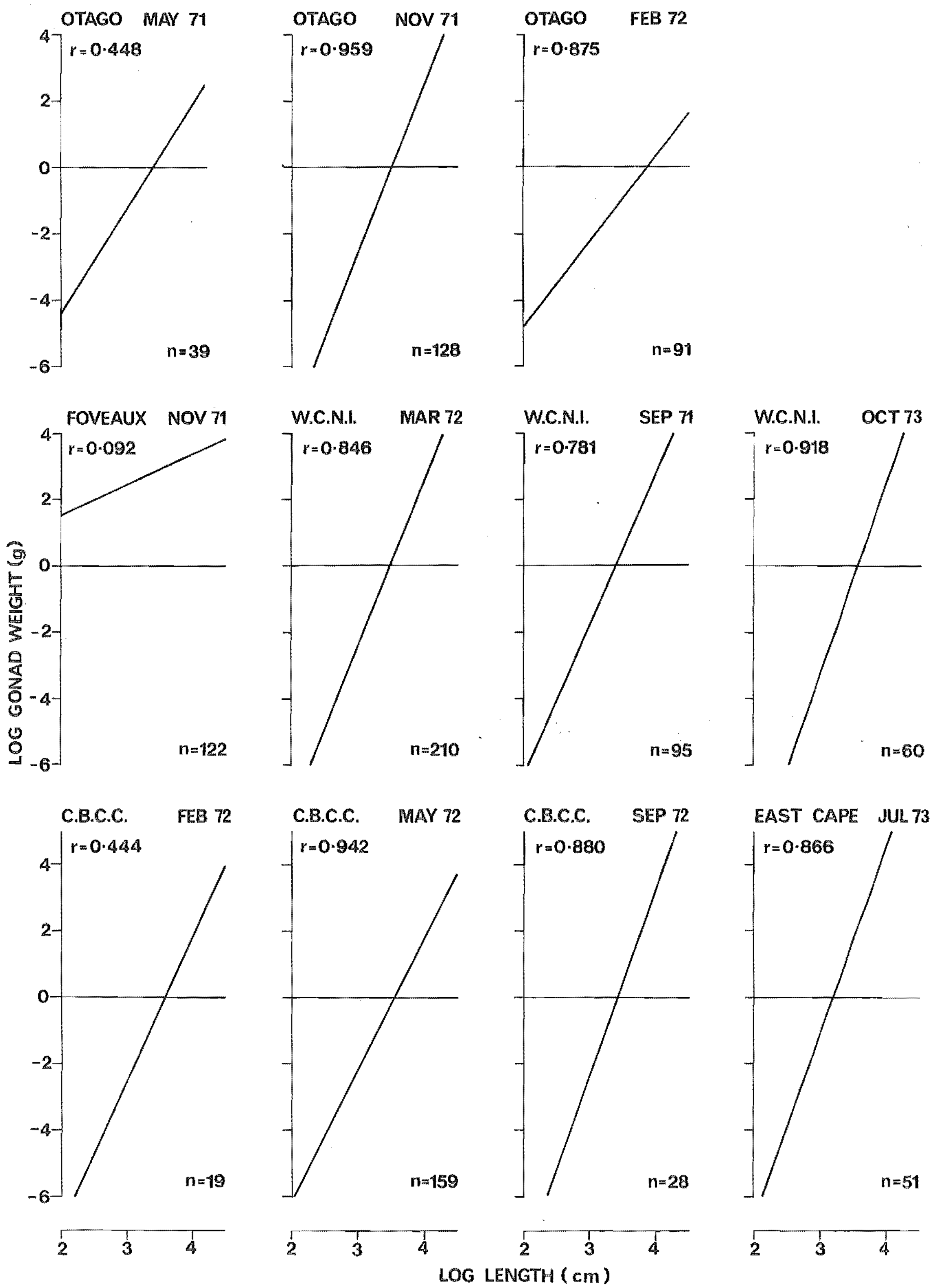
For Otago, the May and November 1971 samples contained mature fish. The low M value of 0.65 in May corresponds with the period of non-breeding as indicated by gonad maturity stage analyses (Section 6.3 a ii (1)). Conversely the high M of November (1.05) can be related to this sample containing recently spent fish with relatively larger gonads.

Likewise, similar comparisons can be made between M values and the distribution of gonad maturity stages (Sections 6.3 a ii (2) - 6.3 a ii (6)) for the other areas studied. From a perusal of Table 62,

FIGURE 54

Red cod gonad weight - fish length relationships for samples from other areas (Equations as for Fig. 53, but only a and b values given). For r values, * = significant at 5% level, ** = significant at 1% level, where no entry, relationship not significant.

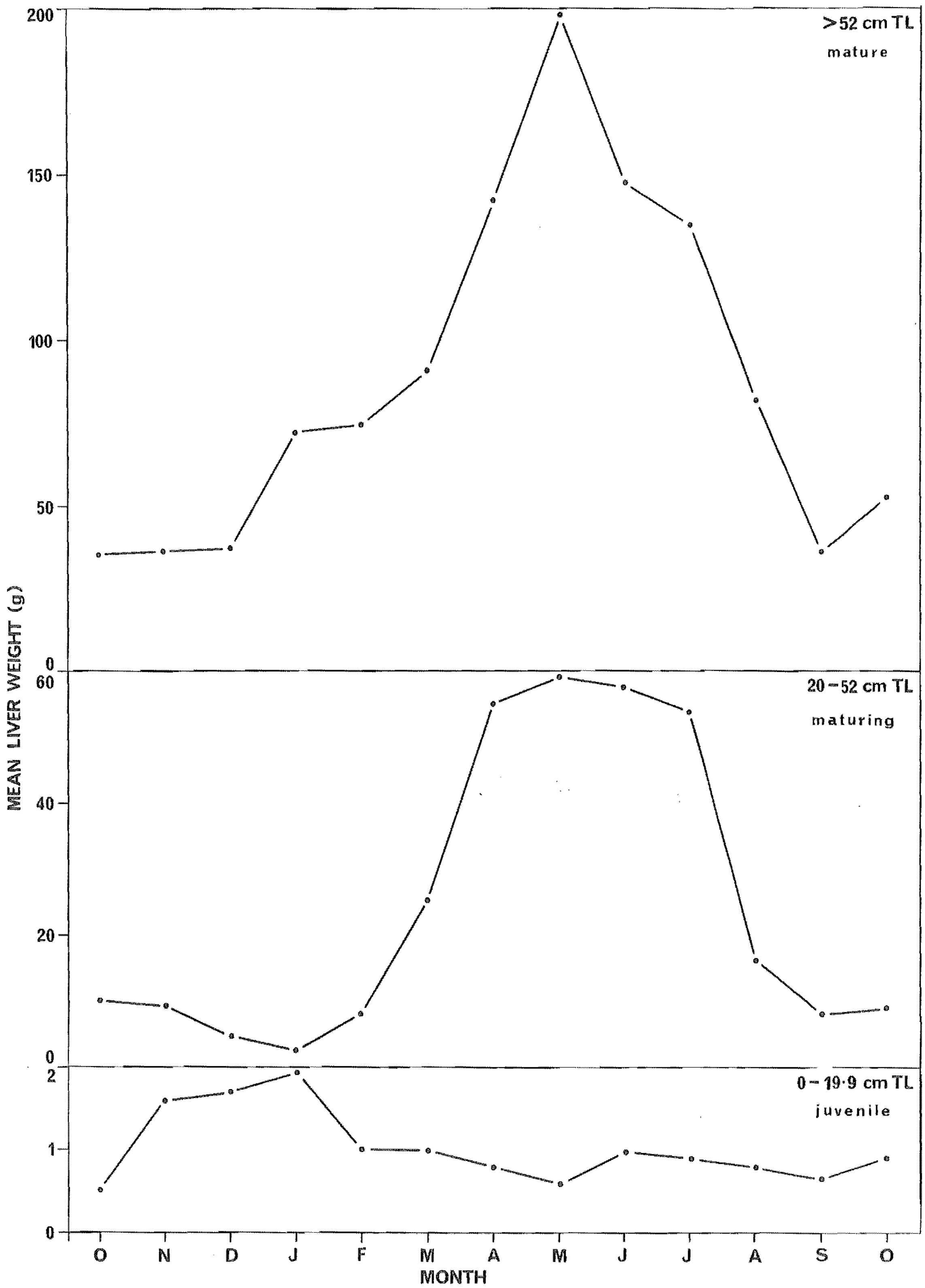
	a	b	r
OTAGO			
May 1971	-11.590	3.372	
November 1971	-18.254	5.179	**
February 1972	-9.857	2.544	**
FOVEAUX STRAIT			
November 1971	-0.260	0.895	
W.C.S.I.			
March 1972	-17.196	4.932	**
W.C.N.I.			
September 1971	-15.616	4.620	*
October 1973	-20.783	5.893	**
C.B.C.C.			
February 1972	-16.645	4.605	
May 1972	-14.603	4.142	**
September 1972	-19.929	5.853	**
EAST CAPE			
July 1973	-17.897	5.640	**



OTAGO MAY 71
r=0·448
n=39
OTAGO NOV 71
r=0·959
n=128
OTAGO FEB 72
r=0·875
n=91
FOVEAUX NOV 71
r=0·092
n=122
W.C.N.I. MAR 72
r=0·846
n=210
W.C.N.I. SEP 71
r=0·781
n=95
W.C.N.I. OCT 73
r=0·918
n=60
C.B.C.C. FEB 72
r=0·444
n=19
C.B.C.C. MAY 72
r=0·942
n=159
C.B.C.C. SEP 72
r=0·880
n=28
EAST CAPE JUL 73
r=0·866
n=51
LOG GONAD WEIGHT (g)
LOG LENGTH (cm)

FIGURE 55

Monthly mean liver weights for juveniles, maturing, and mature red cod in Canterbury samples, October 1971 - October 1972.



MEAN LIVER WEIGHT (g)
>52 cm TL
mature
20 – 52 cm TL
maturing
0 – 19·9 cm TL
juvenile
200
150
100
50
0
60
40
20
0
2
1
0
O
N
D
J
F
M
A
M
J
J
A
S
O
MONTH

it is clear that the M values largely complement the seasonal trends indicated by maturity stage analyses.

As for the Canterbury samples, the log-log relationships between gonad weight and fish length by month for these areas were calculated (Fig. 54).

Analysis of covariance was carried out to compare these sample regressions. However, because of the inherent variation in the samples due to variable sample composition, it was considered that presenting the results of these analyses would be pointless. The regressions therefore simply stand as descriptions of the red cod gonad weight - fish length relationships in these monthly samples.

6.3 c Seasonal variation in liver weight in Canterbury samples, October 1971 - October 1972

Monthly mean liver weights were calculated for juvenile, maturing, and mature red cod in Canterbury samples (Fig. 55). As was found for mean monthly gonad weights, the liver weights of juvenile fish varied little throughout the year. However, for both maturing and mature fish, there were marked seasonal variations in mean liver weight.

There is little doubt that these variations were related to the reproductive cycle (See Shorland, 1950, p. 40; Hoar, 1957, p. 303). The note regarding changes in mean gonad weight in maturing fish (Section 6.3 b i) equally applies to changes in their mean liver weight as a consequence.

Comparing the curves for maturing and mature red cod in Figures 52 and 55, mean liver weights increased rapidly from about December to May during which time gonad weights remained low. From May to September, liver weights decreased rapidly while gonads underwent an equally rapid increase in weight. It is probable that the food reserves in the liver were being utilized for egg production at this time. Numerous workers have made the same assumption for other species (Lühmann, 1953, cited by Love _in_ Brown, 1957; Halliday, 1969b; Ritchie, 1969; Habib, 1971; Cadwallader, 1973). These workers also found that food reserves were lowest immediately after spawning. This was found for red cod (the October - December period).

It has also been found that variations in conditions can be related to feeding periodicity which at times is associated with the reproductive cycle (See numerous references in Homans and Vladykov, 1954; Nikolsky,

FIGURE 56

Red cod liver weight - fish length relationships by month for Canterbury samples (Equations as for Fig. 53, but only a and b values given).

	a	b
1971		
October	-9.009	3.072
November	-11.008	3.682
December	-7.260	2.480
1973		
January	-10.291	3.567
February	-12.265	3.921
March	-10.103	3.443
April	-20.601	6.125
May	-11.492	3.971
June	-11.775	3.990
July	-11.099	3.848
August	-10.703	3.600
September	-8.821	3.001
October	-11.004	3.519

NB: All r values significant at the 1% level

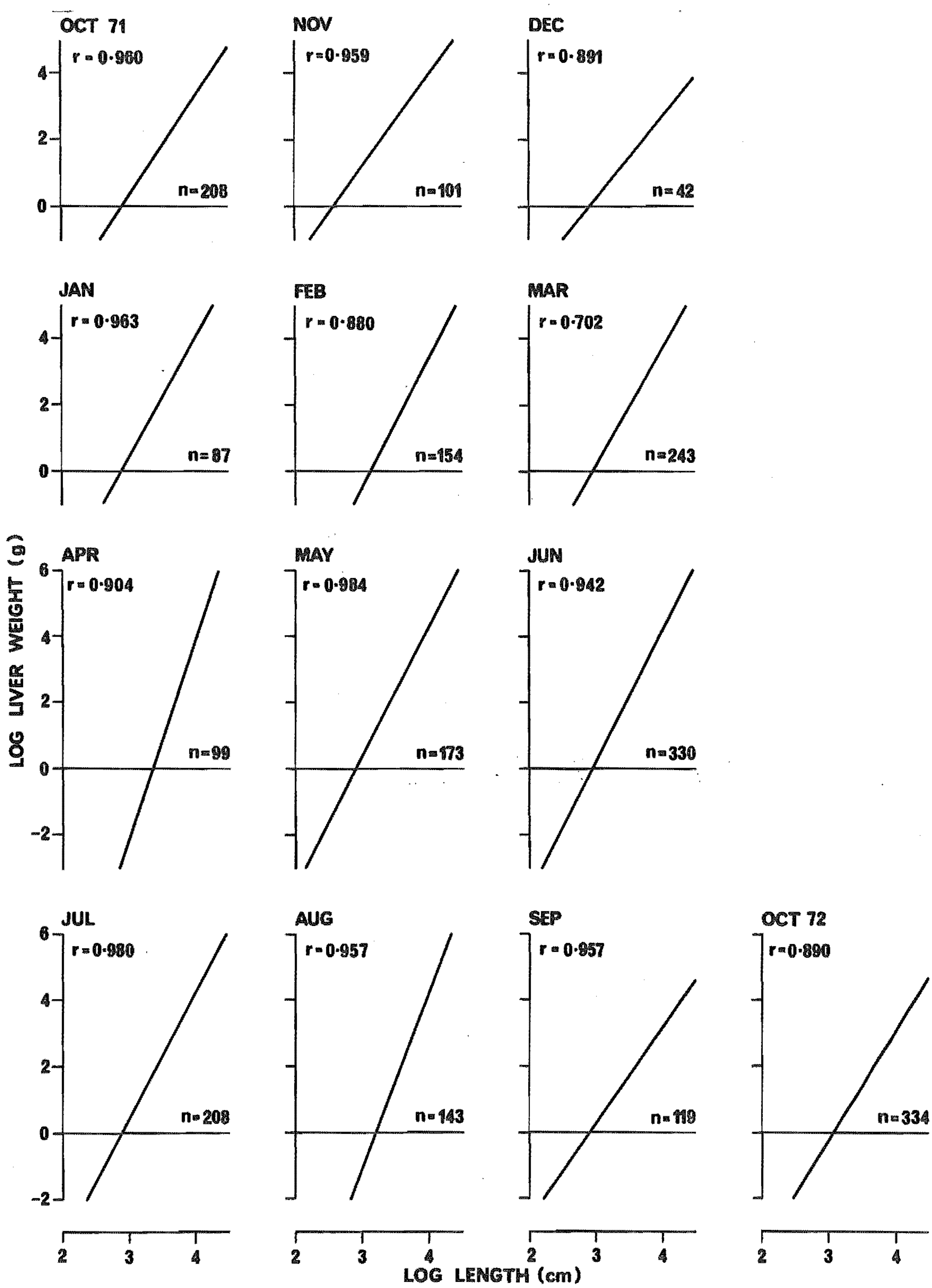

OCT 71
r = 0·960
n = 208
NOV
r = 0·959
n = 101
DEC
r = 0·891
n = 42
JAN
r = 0·963
n = 87
FEB
r = 0·880
n = 154
MAR
r = 0·702
n = 243
APR
r = 0·904
n = 99
MAY
r = 0·984
n = 173
JUN
r = 0·942
n = 330
JUL
r = 0·980
n = 208
AUG
r = 0·957
n = 143
SEP
r = 0·957
n = 119
OCT 72
r = 0·890
n = 334
LOG LIVER WEIGHT (g)
LOG LENGTH (cm)

FIGURE 57

Fecundity of Canterbury red cod related to

a - total length : mean length = 62.1 cm

s = 1.003

mean fecundity = 2 970 081

s = 1.200

r = 0.802**

b - gonad weight : mean gonad weight = 98.77 g

s = 1.152

mean fecundity = 2 970 081

s = 1.200

r = 0.840**

c - gutted weight : mean gutted weight = 1 962.35 g

s = 1.041

mean fecundity = 2 970 081

s = 1.200

r = 0.865**

d - gutted weight by

size class - (i): mean gutted weight = 1 619.87 g

s = 1.016

mean fecundity = 2 370 710

s = 1.163

r = 0.792**

(ii): mean gutted weight = 2 332.28 g

s = 1.007

mean fecundity = 3 575 444

s = 1.146

r = 0.565

(iii): mean gutted weight = 3 454.73 g

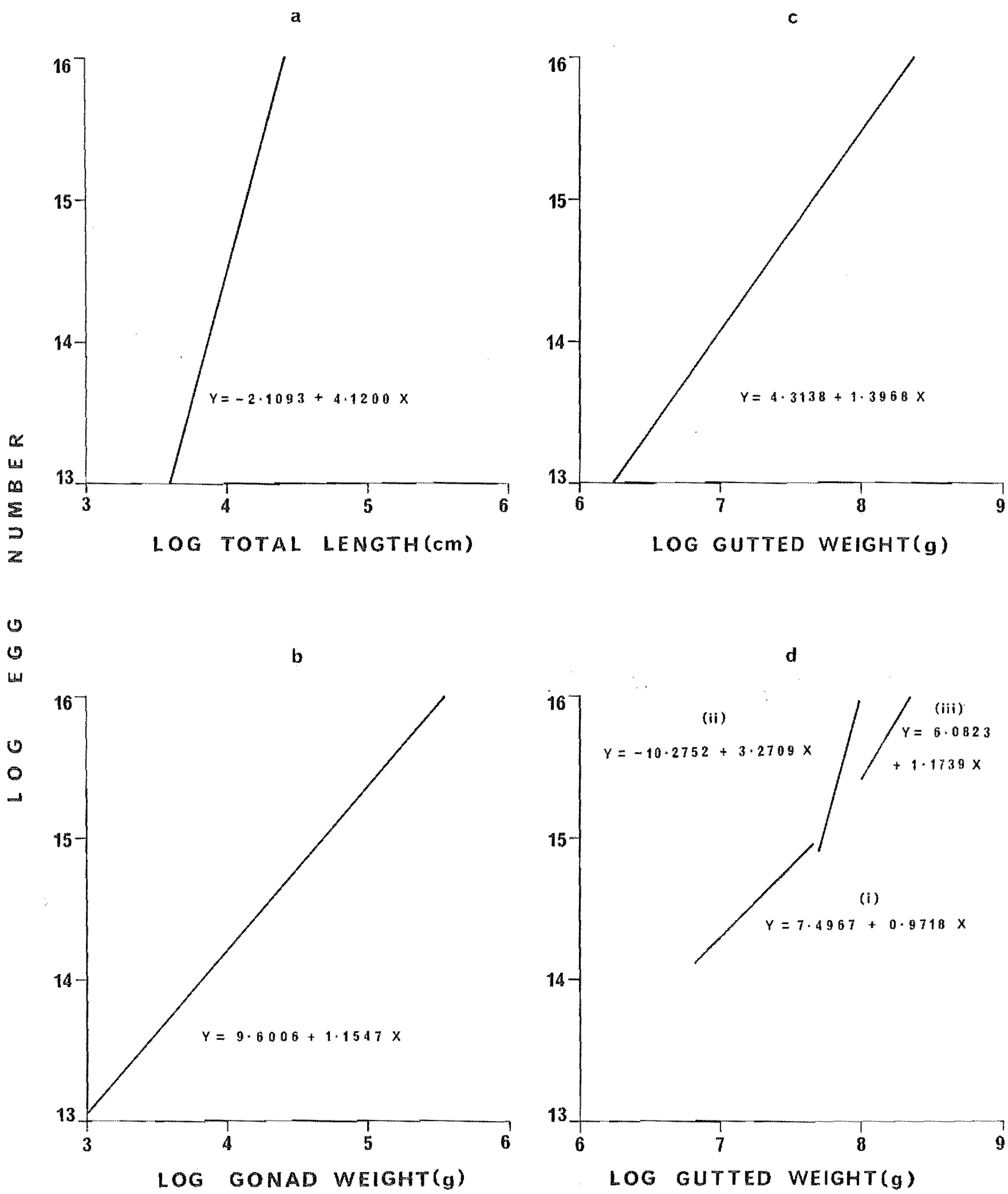
s = 1.004

mean fecundity = 6 242 554

s = 1.081

r = 0.860**

NB: n = 50 for all relationships; s = standard deviation; r = correlation coefficient; ** significant at 1% level.



a
b
c
d
LOG EGG NUMBER
Y= −2·1093 + 4·1200 X
LOG TOTAL LENGTH(cm)
Y= 4·3138 + 1·3968 X
LOG GUTTED WEIGHT(g)
Y= 9·6006 + 1·1547 X
LOG GONAD WEIGHT(g)
(ii)
Y= −10·2752 + 3·2709 X
(iii)
Y= 6·0823
+ 1·1739 X
(i)
Y = 7·4967 + 0·9718 X
LOG GUTTED WEIGHT(g)

1963; Halliday, 1969b). However, whether this applied to red cod could not be determined. Feeding levels were generally low for all Canterbury samples (See Section 5) and no feeding periodicity was apparent.

It should be noted that my results contrast markedly with those of Carter and Malcolm (1926) (See Section 6.2 c). It is possible that their interpretations were in error because of the small size of their samples and the limited periods of the year in which these were obtained.

To describe the relationships between liver weight and fish length in the Canterbury samples, log-log regressions were calculated (Fig. 56). Analysis of covariance was used to compare regression lines. Results of these analyses are presented in Table 63.

There were few similarities between the samples. Variances were homogeneous between only 5 of the 13 pairs of months compared. In only 2 pairs of months were there any further similarities, this in slopes. It is probable that the non-comparability in these samples was owing to the variability in samples (See Section 6.3 b i).

6.3 d Seasonal variation in egg size

Seasonal variation in egg size was directly related to seasonal variation in gonad maturity stages (Table 58). Comments on the latter variation in Section 6.3 a also include variation in egg size. Egg size did not noticeably vary with area.

6.3 e Fecundity

6.3 e i Canterbury samples

Gonads from 50 gravid red cod, captured during the period July - October 1972, were set aside for fecundity studies. Fecundity was analysed in relation to red cod total length (Fig. 57a), gonad weight (Fig. 57b), gutted weight (Fig. 57c), and gutted weight of the red cod size classes 52-59.9 cm total length (Fig. 57di), 60-67.9 cm (Fig. 57dii), and $>$68 cm (Fig. 57diii). These size classes were chosen arbitrarily with a view of showing any internal differences in the fecundity/gutted weight relationship (See also Nagasaki, 1958; May, 1967; Bagenal, 1969; Habib, 1971).

Table 63: Analysis of covariance testing of comparative combinations of red cod liver weight fish length regressions, Canterbury samples (Key to numbers in comparative combinations: 1-13 = October 1971 - October 1972; for all testing, P = < 0.01).

Comparative combination	Variances homogeneous	χ^2	Common slope	F	Common intercept	F	Regression coefficients for combination
1 + 2	x		x		x		
2 + 3	√	5.16687	x		x		
3 + 4	√	2.16989	x		x		
4 + 5	√	5.56730	√	3.00702	x		
5 + 6	x		x		x		none
6 + 7	√	1.98283	x		x		
7 + 8	x		x		x		
8 + 9	√	0.39003	√	2.17951	x		
9 + 10	x		x		x		
10 + 11	x		x		x		
11 + 12	x		x		x		
12 + 13	x		x		x		
1 + 13	x		x		x		

Fecundity on length has been described by many workers and they have concluded that the form of the relationship is:

$$F = aL^{b}$$

where F = fecundity, L = fish length, and a and b are constant and exponent derived from the data. This involves logarithmic transformation and the fitting of straight line regressions of log fecundity on log length. As larger fish tend to be more variable in their fecundities than smaller ones, logarithmic transformation of the data is desirable as it stabilizes the variances of the regression lines (Pope, Mills and Shearer, 1961; Bagenal, 1966, 1968). Logarithmic transformation was carried out for all relationships earlier outlined.

Typically, fecundity has been shown to be approximately proportional to the cube of fish length, that is, the exponent b approximates 3. Bagenal (1966) observed that although b values for various fish range from 2.34 to 5.28, the most usual values are about 3.

In this study, b was substantially greater than 3. The equation describing the relationship of fecundity on length was:

$$F = -2.1093\ L^{4.1200}$$

(Fig. 57a). There was close agreement between the variables in this relationship as is indicated by the correlation coefficient (0.802). Red cod of mean length (62.1 cm) in the sample analysed contained about 2 970 081 ripening eggs.

Unlike the cubic relationship between fecundity and length, the relationship between fecundity and weight in fish is typically linearly proportional (Kusakabe, Murakami and Onbe, 1962; Hodder, 1963; Pitt, 1964; Bagenal, 1966, 1968; May, 1967).

The fecundity-gutted weight (W) relationship for red cod, using the equation outlined for fecundity on length was:

$$F = 4.3138\ W^{1.3968}$$

(Fig. 57c). These variables were closely related ($r = 0.865$). For a fish of mean gutted weight (1 962.35 g), the fecundity was about 2 970 081.

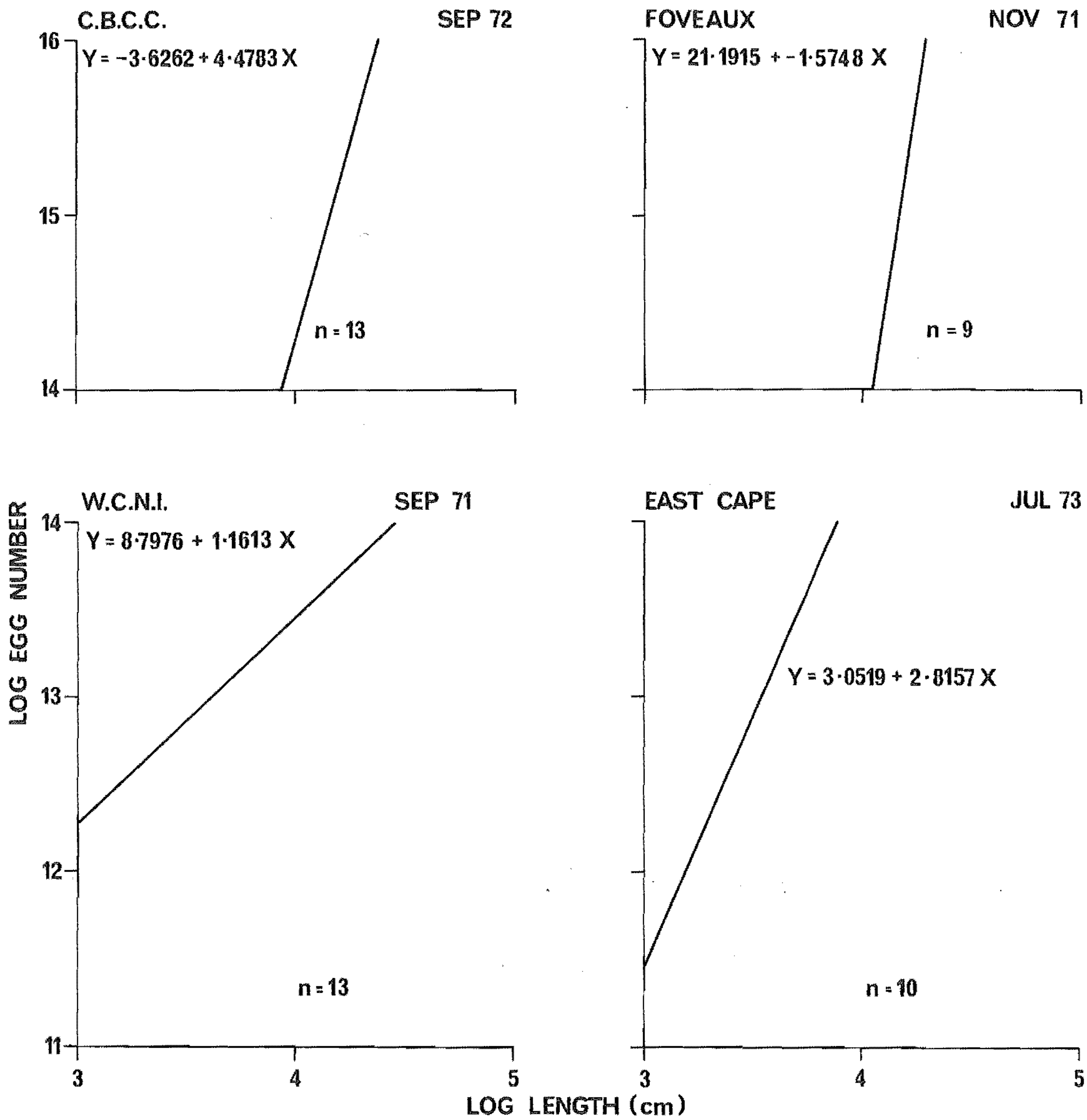
Similar linear relationships were found between fecundity and gutted weight for 52-59.9 cm fish, and for >68 cm fish (Fig. 57di and ii). However, for the 60-67.9 cm fish, the relationship was somewhat

FIGURE 58

Fecundity/length relationships for red cod samples from the areas:

C.B.C.C. -	mean length	= 60.5 cm
	s	= 1.003
	mean fecundity	= 2 542 605
	s	= 3.444
	r	= 0.448
FOVEAUX STRAIT -	mean length	= 62.0 cm
	s	= 1.000
	mean fecundity	= 2 398 610
	s	= 3.025
	r	= 0.126
W.C.N.I. -	mean length	= 33.5 cm
	s	= 1.037
	mean fecundity	= 390 546
	s	= 1.210
	r	= 0.568
EAST CAPE -	mean length	= 28.4 cm
	s	= 1.039
	mean fecundity	= 261 607
	s	= 1.440
	r	= 0.740

NB: s = standard deviation; r = correlation coefficient.


C.B.C.C.
SEP 72
Y = -3·6262 + 4·4783 X
n = 13
FOVEAUX
NOV 71
Y = 21·1915 + -1·5748 X
n = 9
W.C.N.I.
SEP 71
Y = 8·7976 + 1·1613 X
n = 13
EAST CAPE
JUL 73
Y = 3·0519 + 2·8157 X
n = 10
LOG EGG NUMBER
LOG LENGTH (cm)

more than cubic (Fig. 57dii). For many fecundity/weight relationships, it is common to find considerable internal variation between the variables. The above divergent size class indicates the section of the fecundity-gutted weight relationship (Fig. 57c) in which this variability is greatest.

Fecundity has occasionally been related to gonad weight (e.g. Bagenal, 1957, 1969; Pitt, 1964; Colman, 1973). Fecundity has been found to be less than proportional to gonad weight (GW). For the red cod, the equation describing the relationship was:

$$F = 9.6006\ GW^{1.1547}$$

(Fig. 57b). These variables were closely correlated ($r = 0.840$). For red cod containing gonads of mean weight 98.77 g, the fecundity was about 2 970 081.

The above analyses show that for estimating fecundity in red cod, the use of data on fish lengths, gutted weights and gonad weights are almost equally reliable. Because length is the easiest to measure, it is obviously the most suitable for predicting fecundity in red cod.

6.3 e ii Other area samples

Bearing in mind the findings for the Canterbury samples, fecundity in small samples from Foveaux Strait, W.C.N.I., C.B.C.C., and East Cape was related to red cod length (Fig. 58), after logarithmic transformation.

It was only in the East Cape sample that b approached the expected value of 3: this parameter was considerably greater than 3 in the C.B.C.C. sample and less than 3 in the samples from Foveaux Strait and W.C.N.I. In none of the relationships was r significant. Obviously, the small size of the samples imposes limitations on the use of these results in fecundity studies. However, as part of a preliminary investigation, the means of fish length and fecundity (See facing page, Fig. 58) must have value.

6.3 e iii Comparisons of fecundity

Codfishes characteristically are highly fecund "... with many species carrying over 1 000 000 eggs" (Marshall and Cohen, 1973) (See also Svetovidov, 1948; and Breder and Rosen, 1966).

Graham (1939) estimated the fecundity of three red cod from Otago waters. His counts were 2 600 000, 3 350 000, and 4 900 000. This is the only previous work on this aspect of red cod biology.

In this study, fecundity ranged from 102 000 to 6 270 000 in samples from five stations around New Zealand (Table 64).

Table 64: Ranges of red cod lengths and fecundity by area (fecundity to nearest thousand).

Area	Range in length (cm)	Range in fecundity (thousands)
CANTERBURY	52.0 - 74.0	1 300 - 6 270
C.B.C.C.	52.6 - 68.9	1 160 - 5 525
FOVEAUX STRAIT	58.0 - 65.6	2 341 - 3 654
W.C.N.I.	36.3 - 48.09	178 - 743
EAST CAPE	28.0 - 47.0	102 - 986

Fecundity varied greatly between cod from North and South Island areas but remained relatively constant within North Island and South Island waters respectively. As was demonstrated in Section 6.3 a, there was an increase in size of spawning fish from north to south in New Zealand waters. Concomitant with this increase was a great increase in fecundity. As there were no differences between areas in size of mature eggs (Section 6.3 d), the differences in fecundity were probably a function of the size of the gonads. It was demonstrated in Figure 52 that big fish have heavier gonads than small fish. And Figure 57b showed that there is a good relationship between fecundity and gonad weight. While these figures are based on Canterbury data, the points they illustrate probably apply to samples from all areas.

6.3 f Plankton samples

Information on all plankton samples collected during the study is presented in the appendices. In 25 samples collected from the Canterbury area during the period 5.5.71 to 21.10.72, no eggs or larvae of red cod were found. However, eggs were tentatively identified in the samples collected in the C.B.C.C. area during October, 1971.

The failure to collect red cod eggs and larvae (apart from the above tentative recording) is not surprising. Dr D.A. Robertson, who conducted an extensive survey of planktonic eggs and larvae of New Zealand marine teleosts during 1970-1972, also failed to collect red cod eggs and larvae (See Robertson 1973, p. 107). If, as indicated in Section 6.1, red cod spawn in offshore waters, it is conceivable that their eggs and larvae were present beyond the plankton stations occupied by me and Dr Robertson.

6.3 g Juvenile red cod

Concentrations of these fish, as reported by various workers (Section 6.1), were not found during this study.

6.3 h Sex ratios

Although much of the analysis in this section was carried out on samples in which the sexes were combined, sex ratios are a relevant aspect of the reproductive biology of red cod. The composition of all samples by sex is presented in Tables 27-33. Sex ratios by area by month, for all months by area, and for all samples combined are presented in Table 65.

Of 3 357 red cod sexed, 52.43% were male, and 47.57% female, the ratio being 1 female to 1.10 males. In 14 of the 25 monthly samples, males predominated. This was also generally the case for samples from the areas Canterbury, W.C.S.I., C.B.C.C., and East Cape. Females generally predominated in the other areas studied.

Table 65: Sex ratios of red cod (F = female, M = male).

Area		Ratios F : M	Ratios M : F	Total fish
CANTERBURY	Oct 1971	1 : 1.31		210
	Nov "		1 : 1.76	102
	Dec "	1 : 1.44		44
	Jan 1972		1 : 1.32	88
	Feb "	1 : 2.18		156
	Mar "	1 : 1.64		248
	Apr "	1 : 3.12		107
	May "	1 : 1.54		175
	Jun "	1 : 1.16		330
	Jul "	1 : 1.44		210

Table 65: Continued

Area		Ratios F : M	Ratios M : F	Total fish
CANTERBURY	Aug 1972	1 : 1.60		143
	Sep "		1 : 2.61	119
	Oct "		1 : 1.02	362
	All months	1 : 1.24		2 294
OTAGO	May 1971		1 : 1.17	39
	Nov "		1 : 3.27	128
	Feb 1972	1 : 1.68		91
	All months		1 : 1.50	258
FOVEAUX	Nov 1971		1 : 5.78	122
W.C.S.I.	Mar 1972	1 : 1.76		210
W.C.N.I.	Sep 1971	1 : 1.11		95
	Nov "		1 : 2.00	48
	Oct 1973		1 : 2.75	60
	All months		1 : 1.48	203
C.B.C.C.	Feb 1972		1 : 2.17	19
	May "	1 : 1.89		165
	Sep "		1 : 3.37	35
	All months	1 : 1.26		219
EAST CAPE	Jul 1973	1 : 1.43		51
ALL AREAS	ALL MONTHS	1 : 1.10		3 357

6.4 Summary

1 An account of previous work on reproduction in red cod is given and various personal communications reported.

2 Using a part qualitative/part quantitative classification scheme, monthly percent occurrence of female and male gonads at different stages of maturity were recorded. Because there were no differences in maturity between male and female fish, all percentages were combined. In Canterbury samples, gravid fish, which were first present in July, were in peak abundance in August, as were spawning fish in August-September, spent fish in November, and recovering spent fish in January. Indications were that the spawning period was similar in all areas.

3 A seasonal movement of spawning red cod into offshore waters was indicated by the pattern of catches of this species in inshore and offshore waters before, during, and after the spawning period. Further evidence of this movement was provided by various personal communications involving the distribution of juvenile red cod in offshore waters after the spawning season.

4 Size at first maturity was similar in Canterbury, Otago, Foveaux Strait and C.B.C.C. samples (> 52 cm). However, in W.C.N.I. samples, red cod were mature from 36 cm, in East Cape samples, from 28 cm in length. This parameter could not be ascertained for the W.C.S.I. sample.

5 Seasonal variations in gonad weight, maturity coefficient (M), and log-log regressions of the relationship gonad weight-fish length were demonstrated in relation to the different areas studied. These variations lend support to the descriptions of the periods of breeding and non-breeding in gonad maturity stage analyses.

6 Seasonal variation in liver weight as a measure of condition in the Canterbury samples is presented. Mean liver weights increased rapidly from about December to May, but from May to September, mean weights rapidly decreased. It is suggested that food reserves in the liver were being utilized for egg production in the gonads during this period of decrease. A relationship between seasonal variation in liver weight and feeding cycles could not be determined. Seasonal variations in the log-log relationship liver weight - fish length were found. However, because of variability in the composition of the samples, they were generally non-comparable in terms of this log-log relationship.

7 Fecundity estimates were made from counts of small egg samples representing a fraction of the gonad with subsequent appropriate multiplication. In Canterbury samples, these estimates were related to red cod length, gonad weight, gutted body weight, and to gutted weight of the three size classes of fish 52-59.9 cm, 60-67.9 cm, and > 68 cm in length. All relationships were close except for the fecundity/gutted weight relationship of 60-67.9 cm fish. Fecundity in Canterbury samples ranged from 1 300 000 - 6 270 000 eggs.

In samples from other areas, fecundity was related only to length. There was great variation in this relationship, with no relationship being significant. Fecundity ranged from 102 000 - 5 525 000 in samples from these other areas.

Fecundity was highest in South Island area samples. As the gonads in southern red cod were larger than those in their northern counterparts, it is suggested that the increase in fecundity from north to south was correlated with the increase in gonad size.

8 Information on plankton samples is presented. In 30 samples collected during the period 5.5.71-29.10.72 from Canterbury and C.B.C.C., there were only two tentative recordings of red cod eggs, and none of red cod larvae. No concentrations of juvenile red cod were found.

9 Of 3 357 red cod sexed during the study, 52.43% were male, and 47.57% female, giving a ratio of female to male of 1 : 1.10.

SECTION 7

CONCLUSIONS

The aim of the study was to gain an understanding of the biology and ecology of the red cod *Pseudophycis bacchus* in New Zealand waters. The red cod is a predominantly bottom-dwelling omnivorous fish which is distributed in the coastal and offshore waters of New Zealand, more abundantly to the south of this range. Comprising up to 5% of the New Zealand total wetfish landings, it has some commercial importance. Information on the biology and ecology of a fish stock is necessary for its rational exploitation and management. It was the realization of this necessity together with a knowledge of the paucity of information available on red cod which prompted this study.

During the period May 1971 - October 1973, 8 131 red cod were taken by bottom trawl from seven study areas (Canterbury 4 384; Otago 403, Foveaux Strait 142, West Coast South Island [W.C.S.I.] 227, West Coast North Island [W.C.N.I.] 2 019, Cloudy Bay-Cape Campbell [C.B.C.C.] 905, East Cape 51). All fish were used in length frequency analyses for age and growth: 3 357 (Canterbury 2 294, Otago 258, Foveaux Strait 122, W.C.S.I. 210, W.C.N.I. 203, C.B.C.C. 219, East Cape 51) were used in studies on food and feeding, and reproduction. Samples of Canterbury red cod (160 fish), and related codfishes (*Pseudophycis breviusculus, P. marginatus, P. barbatus, Lotella rhacinus, Salilota australis*) from Canterbury and other areas were used in studies on the taxonomy and systematics of the red cod and its close relatives.

Canterbury samples were collected monthly from October 1971 to October 1972. Samples from other areas were collected as the opportunity arose (Otago - May and November 1971, February 1972, Foveaux Strait - November 1971, W.C.S.I. - March 1972, W.C.N.I. - September and November 1971, October 1973, C.B.C.C. - February, May and September 1972, East Cape - July 1973).

Sixteen trawlers were used in sampling (length range 7-42 m). These vessels employed a wide range of gear (codend mesh size 1.9-11.4 cm) and towed at varying speeds (2.0-4.8 knots). With such variation in gear and methods of operation, selectivity occurred in fishing which yielded samples representing variable fractions of the red cod populations in the different areas. Although the effects of this selectivity were lessened by the analysis of as wide a range of sizes as possible in the different areas, sample compositions were often not comparable. Bearing in mind the variation in the samples, studies were made on all monthly samples, and where month of sampling coincided, comparisons were made between red cod from the different areas.

There were two reasons for the large number of trawlers used to catch samples:

1. Red cod were difficult to catch during the period of sampling. Often trawlers would return from fishing with none or only a few specimens. At these times, monthly samples were made up by accumulating a few fish from several vessels;

2. A large number of areas was studied.

The study areas were defined and information presented on their hydrology and oceanic circulation from my findings and other sources. It was hoped that this information could be tied to biological information to elucidate the ecological relationships of the red cod. However because so many of the biological findings were tentative, it was difficult and at times not possible to comment on the ecological relationships.

The commercial fishery for red cod was investigated by analysing New Zealand Ministry of Agriculture and Fisheries fish landing statistics for the period 1936-1973. Most red cod are landed by trawler although various other methods are employed (nets, lines, seines). Fishing effort increased steadily from 1936 to 1973 but landings fluctuated widely. This was probably related partly to fluctuations in the market for red cod and partly to its availability. Of relevance to this study is that red cod landings were low during 1971-1972, the period of sampling. This might explain why difficulty was experienced in obtaining samples.

The centre of abundance of red cod in New Zealand waters is Canterbury. Considerable quantities are also taken in other South Island areas. In all North Island waters except those adjacent to the north of the South Island (W.C.N.I.), landings are small. By comparing data on Japanese and New Zealand landings of red cod from New Zealand waters, it would seem that this species is distributed most abundantly in offshore waters. Any future effort to catch red cod should be directed by these findings.

In most fish studies, it is essential to establish the precise identification of the species under observation. Often this is difficult because many original descriptions are inadequate. A review of the literature on red cod revealed considerable confusion in its classification and in its systematic position in relation to closely related codfishes of the family Moridae. From 1801 to 1974, red cod was referred to under 15 synonyms by 193 authors. Based on recent taxonomic work on the Moridae and on my own research, it is believed that the correct name for the red cod is *Pseudophycis bacchus* (Forster in Bloch and Schneider, 1801).

From meristic and morphometric analyses, red cod was found to be distinguishable from closely related species by its red-grey elongated form, square-cut tail, body proportions (head moderate, rather broad, depressed above the eye, 24% of standard length; snout depressed, pointed in juveniles, bluntly pointed in adult fish, 26% of head length; orbit large, near to upper profile of head, 21% of head length, 5% of standard length; post-orbital head length 13% of standard length; inter-orbital space broad and flat, 34% of head length; upper jaw length 52% of head length, 13% of standard length), the number of rays in its fins (first dorsal 9-12, second dorsal 39-48, anal 40-50, caudal 32-36, pectorals 22-26, pelvics 5-6), the number of rakers on the first gill arch (upper arm 3-6, lower arm 9-13), the number of pyloric caeca (6-7), the small barbel near the tip of the lower jaw, and by the black spot on the side of the body near the pectoral fins.

Most of the meristic and morphometric analyses on red cod were on Canterbury samples. There is a need for further analyses of samples from other areas to ascertain whether red cod vary geographically. Observations on larger and more wide ranging samples of the closely related codfishes are also required to support my preliminary findings on their taxonomic and systematic relationships with red cod. This type of work must eventually include information on the biology and ecology of all species concerned.

The ability to determine the age of fish is important in fisheries biology. Age data, in conjunction with length and weight measurements can give information on stock composition, age at maturity, life span, mortality, growth and production. Most frequently, age is determined by the interpretation and counting of growth zones in hard parts of fishes. Often this method is used in conjunction with the analysis of multimodal length frequency distributions of samples of fish populations.

In this study only length frequency analyses were carried out. This was because there was not time to age red cod by other means.

Monthly length frequency distributions of 8 131 red cod from all study areas were plotted and the more obvious modes characterized by the probability paper method. Because a wide range of sampling gear was employed in obtaining samples, modes were often unclear in the distributions. However, for Canterbury samples, there were sufficient discrete monthly modes to allow a tentative estimate of 20 cm growth in length in both the first and second years of life. Samples from other areas were inadequate and too discontinuous for growth to be estimated from length frequencies. However based on similarities between modes in corresponding monthly length frequencies, red cod populations from Otago, W.C.S.I., W.C.N.I., and C.B.C.C. may differ little in size composition and growth rate from the Canterbury population. Cod from these areas reached almost 80 cm in length and 5 kg in weight. East Cape cod on the other hand were clearly smaller, reaching 47 cm in length and about 1 kg in weight. It is considered that the small East Cape sample was representative of the area for two reasons:

1. Considerable effort (13 h trawling over 7 days by the large research vessel "James Cook") was used at various stations throughout the area to obtain samples;

2. Other researchers in this area have only ever caught small red cod.

An examination of the relationship between fish length and weight is commonly carried out in age and growth studies. Growth is usually estimated in terms of fish length. From the length-weight relationship, growth in length can be readily converted to growth in weight. Length-weight relationships were calculated for all monthly samples of red cod. However, until reliable estimates of growth are calculated for all areas sampled, this information is of limited value, even for the extensive Canterbury samples.

Clearly there is a need for more representative monthly samples from all areas if the analyses of length frequencies and length-weight are to provide meaningful results. There is also a need for supplementary information on age and growth.

In food and feeding studies, 134 different food items were found in red cod stomachs. Of these 52 were teleosts, 29 reptant decapod crustaceans, 4 amphipods, 4 isopods, 3 elasmobranchs, 3 urochordates, 2 stomatopods, 1 each of euphausid, mysid, polychaete and echinoderm, and 12 were in the unidentified category. Of these items, 118 were found in Canterbury samples, 42 in Otago, 34 in C.B.C.C., 27 in W.C.S.I., 26 in W.C.N.I., 10 in Foveaux Strait, and 8 in East Cape samples. This decrease in number of items is probably largely related to a similar decrease in sample size for these areas. With larger samples from all areas other than Canterbury, it is possible that as wide a range of food items would have been found in these samples as in Canterbury samples.

On present data, each area could be characterized by the more important food items in the diet. These items in order of importance for each area were Canterbury: *Munida*, bluebonnet, opalfish, seaperch, tarakihi, swimming crabs, tunneling mud crab; Otago: policeman crab, *Munida, Ampelisca chiltoni, Squilla armata, Australomysis* sp., southern kingfish, *Pontophilus australis, Palaemon affinis*; Foveaux Strait: *Munida*; W.C.S.I.: hoki, whiting, lanternfish, seaperch, silverfish; W.C.N.I.: pilchard, *Nauticaris marionis*, tunneling mud crab, ahuru, *Callianassa filholi*, sole sprat, leatherjacket; C.B.C.C.: *Ampelisca chiltoni, Munida, Allorchestes novizealandiae, Australomysis* sp., red gurnard, snapper; and East Cape: *Periclimenes* (*harpilius*) *yaldwyni, Australomysis* sp. and roughy. It is likely these initial findings would be modified by further work.

The wide range of foods taken and the seeming preferences for particular foods in the different areas indicate that red cod can considerably modify their feeding behaviour to accommodate to the prevailing food supply. In conjunction with the analysis of further red cod stomach samples, it would be informative to study the availability of food organisms in the different areas. This would provide indications of where red cod are likely to be found at various times of the year, information of commercial significance. Information would be needed on water temperatures and salinities and on substrate types for defining food species distributions.

From analysis of mean stomach weights, fish length-stomach weight regressions, and stomach fullness indices, feeding levels were investigated. All samples contained small quantities of food. Most fish were less than half full and 40% of all fish contained no food at all. Typically fish which take a wide variety of foods are subjected to fluctuating levels in their food supply. It is possible that the low feeding levels found during this study indicate a downward trend in the food supply. This might have contributed to the decline in red cod numbers which is indicated by the sharp fall in New Zealand red cod landings during 1971-1972, the period during which most of my sampling was carried out. With further sampling and stomach analyses during a period of large landings in the red cod fishery, this view could be tested.

Future work should include investigations of the relationships between feeding and growth, development and reproduction; such investigations should also take into account the effects of changing environmental parameters in the different areas at different times of the year. Feeding relationships between red cod and other competing species also need investigation. In view of the wide range of habitats utilized by red cod the number of competing species is likely to be considerable.

Various latitudinal gradations were found in the reproductive biology of red cod. Northern fish (East Cape and W.C.N.I.) reached maturity at a smaller size ($\simeq$ 28-36 cm c.f. $\simeq$ 52 cm), spawned earlier (from July c.f. from August), and released fewer eggs (< 1 million c.f. up to 6 million) than southern cod (e.g. Canterbury). Analysis of further samples from all areas is necessary to substantiate these findings. Through age and growth studies, the relationships between age and size at maturity for northern and southern cod could also be established.

These latitudinal gradations, together with observations of latitudinal differences in red cod landings and fish size may be considered together. Conceivably, northern cod mature earlier as a result of a higher rate of metabolism caused by living in waters of generally higher temperature compared with cod from southern areas. Often populations within a species which experience higher metabolic rates also have a shorter life span: this could account for northern cod being smaller than southern cod. From observations on cod in the Canterbury area, spawning increases as the water temperature rises during late winter and spring. If the onset of spawning is temperature dependent, it would occur earlier in northern cod where water temperature rises earlier. Eggs in red cod gonads had the same size range in all samples. However as northern cod mature at a smaller size, gonads are smaller and so contain fewer eggs compared with southern cod. As a consequence of lower fecundity, the reproductive potential of northern cod is low and may account for the small landings in northern areas.

For Canterbury samples, the association between the reproductive cycle and seasonal fluctuations in liver weight was investigated. There was evidence that red cod store food in their livers during times of non-spawning and utilize this food in the formation of sexual products prior to spawning. This association still needs to be investigated for other areas.

Considerable difficulty was experienced in finding spawning concentrations of red cod or evidence of spawning. Future work on this aspect should aim at sampling widely on the continental slope east of the South Island during July-December, the pre-spawning to post-spawning period. It is there that suitable feeding conditions (high plankton biomass) for larval fish exist (reported by Russian researchers), and concentrations of juvenile and adult fish have been found (Japanese report, my observations) during this period. In addition samples of plankton should be collected and analysed for red cod eggs, larvae, and for quantities of other organisms which provide food for the larvae. Features of the hydrology and oceanic circulation should be noted, particularly where concentrations of eggs and larvae are found. These stages often prefer a limited range of water temperature and salinity, and they may be distributed widely by ocean currents. The nature of this distributive effect could be investigated and related initially to areas of abundance of juvenile fish, and later to the distribution pattern of adult fish in the New Zealand region.

It is clear that much work is still required on red cod. My findings provide a basis for further work. It should however be realized that much of the work which I have indicated as being necessary would require more facilities, finance, manpower and time than are generally available within university institutions and within the scope of a university student research programme.

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APPENDIX 1

Information relevant to plankton samples collected in the Canterbury area 5.5.71-21.10.72 (For positions other than compass bearings, see Fig. 25; * = tentative identification).

Date	Time	Position	Contents
5.5.71	0930-1030	1317b	No eggs; 1 *Sprattus antipodum* larva
5.5.71	1415-1500	1317a	No eggs; 4 *Tripterygion* sp. larvae
19.6.71	1250-1350	1368a	-
16.6.71	1400-1500	1368b	No eggs; 6 *Tripterygion* sp. larvae, 1 myctophid larva, 1 *Scorpaena cardinalis* larva
20.6.71	1230-1400	1368b	No eggs; 1 *Galaxias maculatus* larva
21.7.71	1355-1425	1317d	7 *Auchenoceros punctatus* eggs, 1 *Pelotretis flavilatus* egg, 1 *S. antipodum* larva, 1 *A. punctatus* larva
27.9.71	0814-0844	1316b	8 *Pseudolabrus** sp. eggs, 1 *S. antipodum* egg, 1 *S. antipodum* larva, 1 gobiesocid larva
29.11.71	1230-1300	1316c	378 *S. antipodum* eggs, 202 *Rhombosolea plebeia** eggs, 13 *A. punctatus* eggs, 7 *P. flavilatus* eggs, 4 anchovy eggs, 1 *Leptoscopus macropygus* egg; No larvae
29.11.71	1410-1440	1316e	34 *R. plebeia** eggs, 46 *S. antipodum* eggs, 6 anchovy eggs, 3 *P. flavilatus* eggs, 3 *A. punctatus* eggs; 6 *S. antipodum* larvae
18.12.71	1750-1820	1317d	15 *Chelidonichthys kumu* eggs, 1 *Seriolella brama* egg; 1 *Tripterygion* sp. larva, 1 *Caulopsetta scapha* larva, 1 unknown
19.12.71	0745-1815	1316c	50 *S. antipodum* eggs, 9 *R. plebeia** eggs, 9 anchovy eggs, 1 unknown; No larvae
20.12.71	1345-1415	1316b	75 *S. antipodum* eggs, 16 *R. plebeia** eggs, 48 anchovy eggs, 1 *P. flavilatus* egg; No larvae
23.12.71	1010-1110	1367b	1 *Novodon convexirostris** egg, 1 *Helicolenus papillosus* larva
28.3.72	1112-1212	1368a	-
28.3.72	1222-1322	1368a	-
11.5.72	1500-1600	42°49.3'S, 173°37'E	10 unknown eggs (1.175 x 1.075 mm, no oil droplets); 10 *G. maculatus* larvae

Appendix 1: Continued

Date	Time	Position	Contents
13.5.72	1800-1900	43°55'S, 172°47'E	-
14.5.72	2330-0300	43°37'S 173°56'E	-
29.8.72	1210-1240	1317d	1 *S. antipodum* egg; 2 *S. antipodum* larvae
29.8.72	1250-1320	1317d	No eggs; 1 premetamorphic flatfish larva (some 10+ mm), 5 *A. punctatus* larvae (3-15 mm), 3 *S. antipodum* larvae, 1 unknown larva
28.9.72	1050-1120	42°59'S, 173°36'E	4 unknown eggs (0.97 mm, 1 oil droplet 0.182-0.212 mm), 1 *Maurolicus muelleri* egg; No larvae
28.9.72	1220-1250	42°53'S, 173°37'E	-
29.10.72	0905-0935	43°32.5'S, 173°59.3'E	27 *M. muelleri* eggs, 2 *Coelorhynchus aspercephalus* eggs, 6 unknown eggs (1.15 mm, 1 oil droplet 0.335 mm), 2 unknown eggs (1.24 mm, 1 oil droplet 0.06 mm), 29 unknown eggs (0.88-0.91 mm, 1 oil droplet 0.152 mm); No larvae
29.10.72	1225-1255	43°40'S, 174°02'E	1 unknown egg (0.85 mm, 1 oil droplet 0.212 mm); 1 *S. antipodum* larva
29.10.72	1655-1725	43°20.4'S, 173°43.4'E	1 unknown egg (0.97 mm, 1 oil droplet 0.152 mm); No larvae

APPENDIX 2

Information relevant to plankton samples collected in the C.B.C.C. area 2.10.71-10.5.72 (* = tentative identification).

Date	Time	Position	Contents
2.10.71	0700-0730	41°26'S, 174°09'E	22 *R. plebeia* eggs, 2 *S. antipodum* eggs, 22 *Pseudolabrus* celidotus* eggs, 2 unknown eggs (0.85 mm, 1 oil droplet 0.20 mm), 5 *Pseudophycis bacchus** eggs; 1 *Tripterygion* sp. larva
2.10.71	0745-0845	41°26'S, 174°13'E	82 *P. celidotus** eggs, 42 *R. plebeia** eggs, 1 *C. kumu* egg, 2 *S. antipodum* eggs, 5 *P. bacchus** eggs, 5 unknown eggs (0.750 mm, 1 oil droplet 0.125 mm); No larvae
3.2.72	1135-1235	41°26'S, 174°10'E	6 unknown eggs (0.70 mm, 1 oil droplet 0.150-0.175 mm); No larvae
3.2.72	1245-1345	41°26'S, 174°21'E	-
10.5.72	1251-1351	41°31'S, 174°11.8'E	35 unknown eggs (0.70 mm, 1 oil droplet 0.175 mm); 3 *Tripterygion* sp. larvae, 1 *G. maculatus* larva